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A Cinematographic and Descriptive Comparison of Three Selected Freestyle Racing Starts in Competitive Swimming.

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A CINEMATOGRAPHIC AND DESCRIPTIVE COMPARISON OF THREE SELECTED FREESTYLE RACING STARTS IN COMPETITIVE SWIMMING

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Submitted to the Graduate Faculty of the
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ABSTRACT

The purpose of this investigation was two-fold. First, an attempt was made to determine which of three competitive freestyle racing starts was the fastest. The three styles studied were: (1) the grab; (2) the arms back; and (3) the circular arm swing starts. Second, a descriptive analysis and comparison of the three starts was rendered. Ten sub-purposes were further presented to reveal the mechanical make-up of each start. The sub-purposes were:

1. To compute and plot throughout the dive the center of gravity of each subject in a plane perpendicular to the lens of the camera.

2. To determine the reaction time of each subject to the starting command.

3. To determine the time interval between the command to start and the instant each subject's feet left the starting block.

4. To determine the total elapsed time for the dive which was from the starting command until the hands first made contact with the water.

5. To determine the take-off angle of the body's center of gravity from the starting block measured

in a plane perpendicular to the lens of the camera.

6. To determine the take-off velocity of the body's center of gravity from the starting block measured in a plane perpendicular to the lens of the camera.

7. To determine the horizontal distance that each subject's center of gravity traversed during airborne flight.

8. To determine the time of airborne flight of each subject's center of gravity.

9. To determine the horizontal distance that each subject traversed during his dive.

10. To plot the trajectory of each subject's wrist in a plane perpendicular to the lens of the camera.

The Dekan Human Performance Analyzer was used to time the first fourteen feet of a start and race as executed by seventy-five age-group swimmers. The subjects were divided into three equal groups with each group representing one of the three starts. From these data an analysis of variance was employed to determine the fastest start. Next, the investigator selected the fastest subject within each group to serve as filming model. The criteria for selection was that each swimmer was representative of the most economical start as indicated by his fast time.

The descriptive and comparative analysis consisted of selected film frames from which an anatomical brief was rendered of body movement. By delivering a summation of the progressive movement patterns every .10 of a second, the mechanics of each start provided information with which to distinguish between correct and incorrect body movements and the cause and effect of them. In addition, the trajectory paths for the wrist and body's center of gravity were compared.

Within the limitations of this study the following conclusions were made:

1. There were no significant differences of speed among the three styles of racing starts.

2. In general the movement patterns exhibited by the three filmed subjects were the same.

3. The angle of take-off of each subject was in a downward direction.

4. Due to the prescribed nature of the arm patterns of each subject the greatest movement discrepancy was noted among the arms and body's center of gravity trajectory.

5. From a mechanical standpoint the grab start appeared to be the simplest. The action of the arms was not as complicated as that of the arms back and circular arm swing starts.

6. However, when selecting a freestyle racing start, swimmers should experiment with all three starts and select the one that is most comfortable and economical to them.

CHAPTER I

INTRODUCTION

BACKGROUND

> Opinion is widely diverse concerning the mechanics of the swimming start from a dive.[1]

Whatever prompted prehistoric man to take to water is a matter of pure conjecture. Perhaps he entered it in pursuit of food, although reasoning would indicate that it was man's retreat from the claws of some predatory animal. Whatever the reason, the art of swimming has evolved through the ages into a scientific and highly competitive sport.

However, swimming has not always been so highly regarded or scientific. In the early part of the twentieth century, for example, there was little evidence of scientific studies involving swimming or, for that matter, the racing start. Apparently, the common practice of the day was to copy the existing style of a champion swimmer and apply those mechanics to other swimmers. Even then most of it was done

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[1] James Counsilman, The Science of Swimming (Englewood Cliffs: Prentice-Hall, 1968), p. 133.

visually and without the scientific tools available. It was as though little regard was given to the advancement and understanding of sound mechanical principles. If the style appeared successful, little effort was expended to discover how or why. Therefore, most coaches only held empirical opinions as to what transpired during the execution of a skill.

Unfortunately, studies contemplated in regard to swimming were prompted by research in other sports. Investigators in swimming were not innovators but followers. Specifically, investigations into the track start prompted corresponding studies of the swimming start. Since both required upsetting the center of gravity to initiate the start, many of the movement principles were thought to be the same. For example, Tuttle, Morehouse, and Armbruster[2] noted the success that runners were having with the use of inclined starting blocks. They investigated the use of inclined starting blocks for swimmers. Prior to that time swimmers had initiated their starts from a flat horizontal surface. The investigators concluded that athletes could not start as fast as from an inclined surface as from a flat horizontal surface.

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[2]W. W. Tuttle, Lawrence E. Morehouse, and David A. Armbruster, "Two Studies in Swimming Starts," Research Quarterly, X, (March, 1939), 89-92.

Today swimming is fast becoming a sport of inches. The swimmer with the fastest start, especially in a race of short duration, has a significant advantage over those that are slow in leaving their marks. However, not every swimmer can be a good starter. Two of the three qualities needed for a good start are largely inherited--good reaction time and strength. The third property is good mechanics. Through understanding of the mechanics involved and practice almost any swimmer can improve his start so that he gets off the starting block faster and farther out. For this reason swimming investigators must initiate and carry through studies that will answer questions relative to the mechanics of swimming. While it is true that a coach need not explain every detail of the dive to his swimmers, it is important that he be knowledgeable concerning the mechanics:

> It has been my experience that athletes are best left without a precise knowledge of the nature of the skill, and need only sufficient detail to correct faults, satisfy curiosity, and inspire confidence. Because they learn their skills through their kinesthetic sensations and interests, more descriptive (if mechanically inaccurate) language in coaching is to be preferred to the jargon of Mechanics. But with physical educators and sports coaches, a knowledge of Mechanics can provide an essential tool with which to distinguish between important and unimportant, correct and incorrect, cause and effect, for human motion must obey the laws of all motion, and

> athletic skill at the highest levels applies these same principles to full advantage.[3]

Most swimming coaches disagree about the mechanics of the freestyle racing dive or whether one is superior to the others. Armbruster,[4] for example, advocated the arms back racing dive. He stated that as the arms were hyperextended at the shoulder joint from their initial back position the center of gravity moved forward. Thus, the initial body movement was started by the arms. Counsilman,[5] on the other hand, implied just the opposite. He maintained that the body's center of gravity would remain at the same point if only the action of the arms was involved. He taught the circular arm swing start and stated that contraction of the anterior muscles of the lower leg and relaxation of the calf muscles caused the body to fall toward the water. Bunn[6] theorized that the center of gravity was best upset by rocking back on the heels.

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[3]Geoffrey Dyson, "The Mechanics of Athletes: Some Aspects of Rotational Movement," Journal of Canadian Association for Health, Physical Education, and Recreation, XXXII, (August-September, 1966), 14.

[4]David A. Armbruster, Robert H. Allen, and Bruce Harlen, Swimming and Diving (Saint Louis: C. V. Mosby Company, 1968), pp. 55-72.

[5]Counsilman, op. cit., pp. 133-141.

[6]John W. Bunn, Scientific Principles of Coaching (Englewood Cliffs: Prentice-Hall, 1959), p. 184.

As the body rocked back, flexion of the trunk occurred. This moved the center of gravity forward, outside the base of support, and started the body falling due to the pull of gravity. Gambril[7] concluded that the center of gravity was best upset by pulling the body off the starting block. This was accomplished by grabbing the front or side of the starting platform and initiating the movement.

It was apparent from the aforementioned studies that coaches were still undecided as to which freestyle racing start was the most economical in terms of speed and mechanics. With such a wide range of opinions concerning the mechanics of the start it was imperative that proper scientific procedures be employed to explore this question.

According to current literature, two of the most practical tools for the timing and the analysis of body movement are the Dekan Human Performance Analyzer and motion picture camera. Maglischo[8] used the Dekan Human Performance Analyzer to time swimmers for the first fifteen feet of a race. With regard to analyzing body movement Plagenhoef stated:

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[7]Donald L. Gambril, Swimming (Palisades: Goodyear Publishing Company, 1969), pp. 53-58.

[8]Ernest Maglischo, "Comparison of Three Racing Starts Used in Competitive Swimming," Research Quarterly, XXXIX, (October, 1968), 604-609.

> The use of motion pictures is probably the best single technique for obtaining kinetic and kinematic data related to whole body motion. Movement can be recorded under a wide range of conditions . . . The composite tracing of multiple motion picture frames can answer such questions as: What is the point of greatest acceleration and what is the point of least acceleration of each body segment? Where is the total body center of gravity for any position during motion?[9]

Glassow supported this thought by stating:

> Pictures of motion taken at high speeds are as essential for physical educators and coaches as is the microscope for the biologists. Most descriptions of sports skills and locomotor skills are based on what the eye can see or what the performer thinks he does. Both have been shown to be erroneous.[10]

Therefore, an attempt was made to time and analyze the three most popular freestyle racing starts in competitive swimming. Two of them, the arms back and the circular arm swing starts, had been utilized by swimmers for many years. The third and newest was the grab start. Hopefully, such a study would reveal the fastest and most economical racing start. An understanding of the mechanics involved in the superior start would help coaches distinguish between correct and incorrect mechanics. Human movement must obey the laws

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[9]Stanley Plagenhoef, "Gathering Kinesiological Data Using Modern Measuring Devices," Journal of Health, Physical Education, and Recreation, XXXIX, (October, 1968), 81.

[10]Howard S. Slusher and Aileene S. Lockhart, Anthology of Contemporary Readings, (Dubuque, Iowa: William C. Brown Company, 1966), p. 59.

of physics and athletic skill at the highest level must be in harmony with these principles.

STATEMENT OF PROBLEM

Literature pertaining to freestyle racing starts revealed incongruent statements regarding the mechanics of different starts and which was fastest, if any. Therefore, the problem of this study was to determine the fastest of three distinct freestyle swimming racing starts and to analyze and compare mechanically the component parts of each one.

The three distinct freestyle racing dives that were investigated were: (1) the grab; (2) the arms back; and (3) the circular arm swing starts. Photographs and corresponding explanations for each of the starts are defined under "Definition of Terms."

PURPOSE OF THE STUDY

The purpose of this study was two-fold. First, an attempt was made to determine which of three swimming freestyle racing starts was the fastest. Second, a descriptive and comparative analysis of the three dives was rendered. Ten sub-purposes extracted those qualities indicative of each start. The sub-purposes were:

1. To compute and plot throughout each dive the center of gravity of each subject in a plane perpendicular to the lens of the camera.

2. To determine the reaction time of each subject to the starting command.

3. To determine the time interval between the command to start and the instant each subject's feet left the starting block.

4. To determine the total elapsed time for the dive which was from the starting command until the hands first made contact with the water.

5. To determine the take-off angle of the body's center of gravity from the starting block measured in a plane perpendicular to the lens of the camera.

6. To determine the take-off velocity of the body's center of gravity from the starting block measured in a plane perpendicular to the lens of the camera.

7. To determine the horizontal distance that each subject's center of gravity traversed during airborne flight.

8. To determine the time of airborne flight of each subject's center of gravity.

9. To determine the horizontal distance that each subject traversed during his dive.

10. To plot the trajectory of each subject's wrist in a plane perpendicular to the lens of the camera.

DEFINITION OF TERMS

Words that were unique to cinematography and swimming must inevitably be used in reporting procedures. Therefore, it was necessary to define and use several terms that facilitated the understanding of this study.

Grab start. The grab start is a style of dive in which the swimmer crouches and assumes a set position with the hands grabbing the leading edge of the starting block. Upon hearing the starting signal the swimmer initiates the dive by forcefully pulling downward and pushing against the block. As the body leaves the block the arms are rotated counter-clockwise to an extended overhead position. Refer to Figure 1 on page 10 for a pictorial illustration of the initial starting position for the grab start.

Arms back start. The arms back start is a style of dive in which the swimmer crouches and assumes a set position with the arms slightly hyperextended. Upon hearing the starting signal the swimmer initiates the dive by vigorously rotating the arms clockwise and then

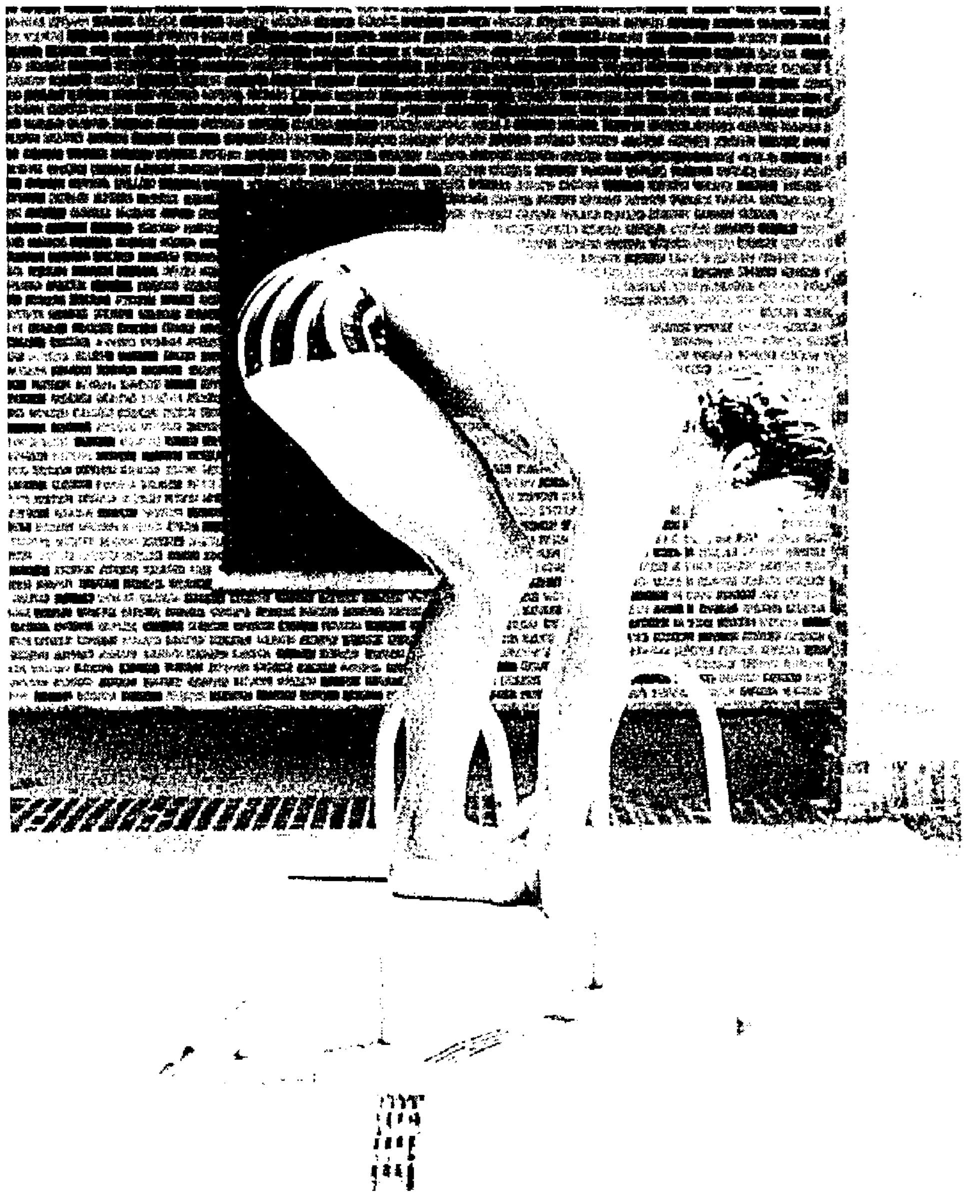

Figure 1. Pictorial Illustration of the Initial Starting Position of the Grab Start.

counter-clockwise to an extended overhead position. Refer to Figure 2 on page 12 for a pictorial illustration of the initial starting position for the arms back start.

Circular arm swing start. The circular arm swing start is a style of dive in which the swimmer assumes a set position with the arms pointing, approximately two feet past the vertical, toward the bottom of the pool. Upon hearing the starting signal the swimmer initiates the dive by vigorously rotating the arms counter-clockwise to an extended overhead position. Refer to Figure 3 on page 13 for a pictorial illustration of the initial starting position for the circular arm swing start.

Cinematography. Cinematography is a scientific procedure used to analyze human performance. Through the use of high speed photography human performance can be recorded and analyzed in terms of mechanical principles.

Center of gravity. The center of gravity is that point at which the effective weight of the body is centered. It is located at the junction of the transverse, frontal, and sagittal planes. However, in this study all calculations will be computed from a plane

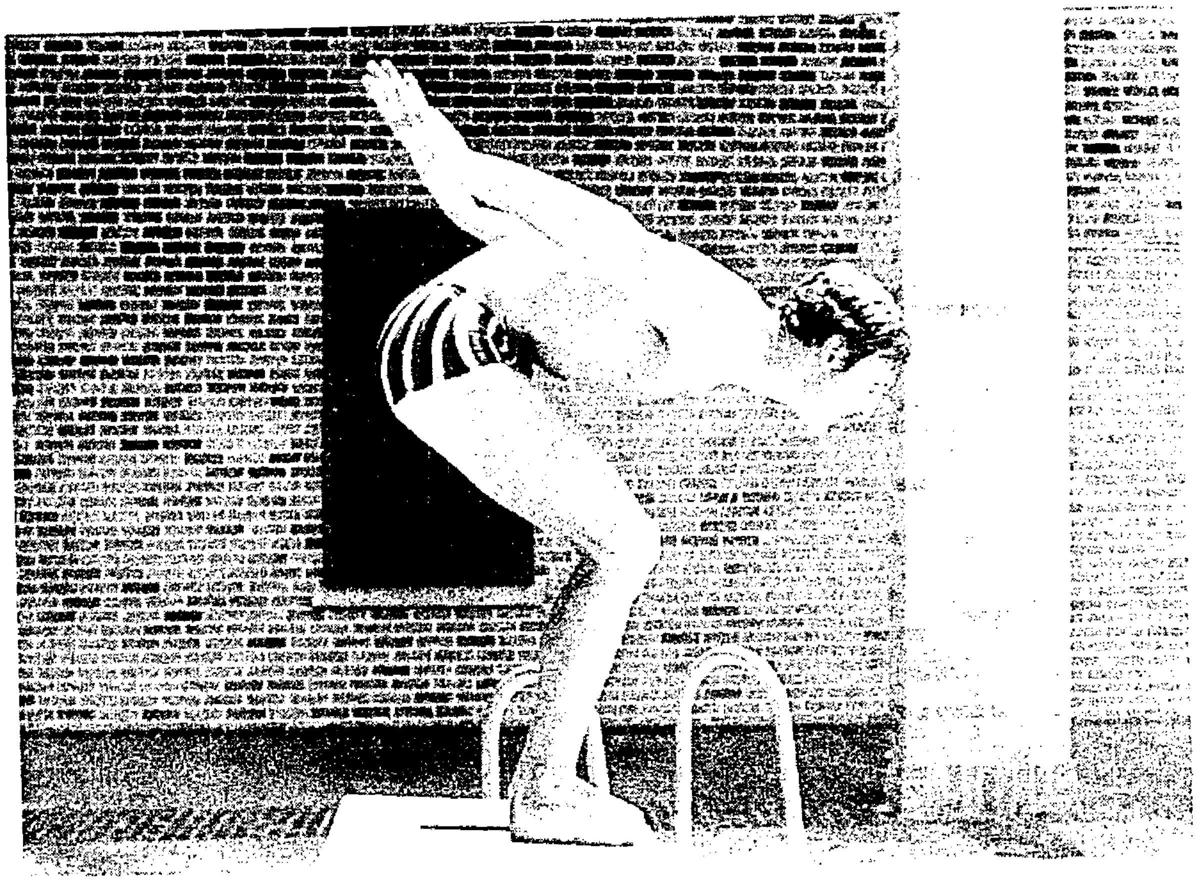

Figure 2. Pictorial Illustration of the Initial Starting Position of the Arms Back Start.

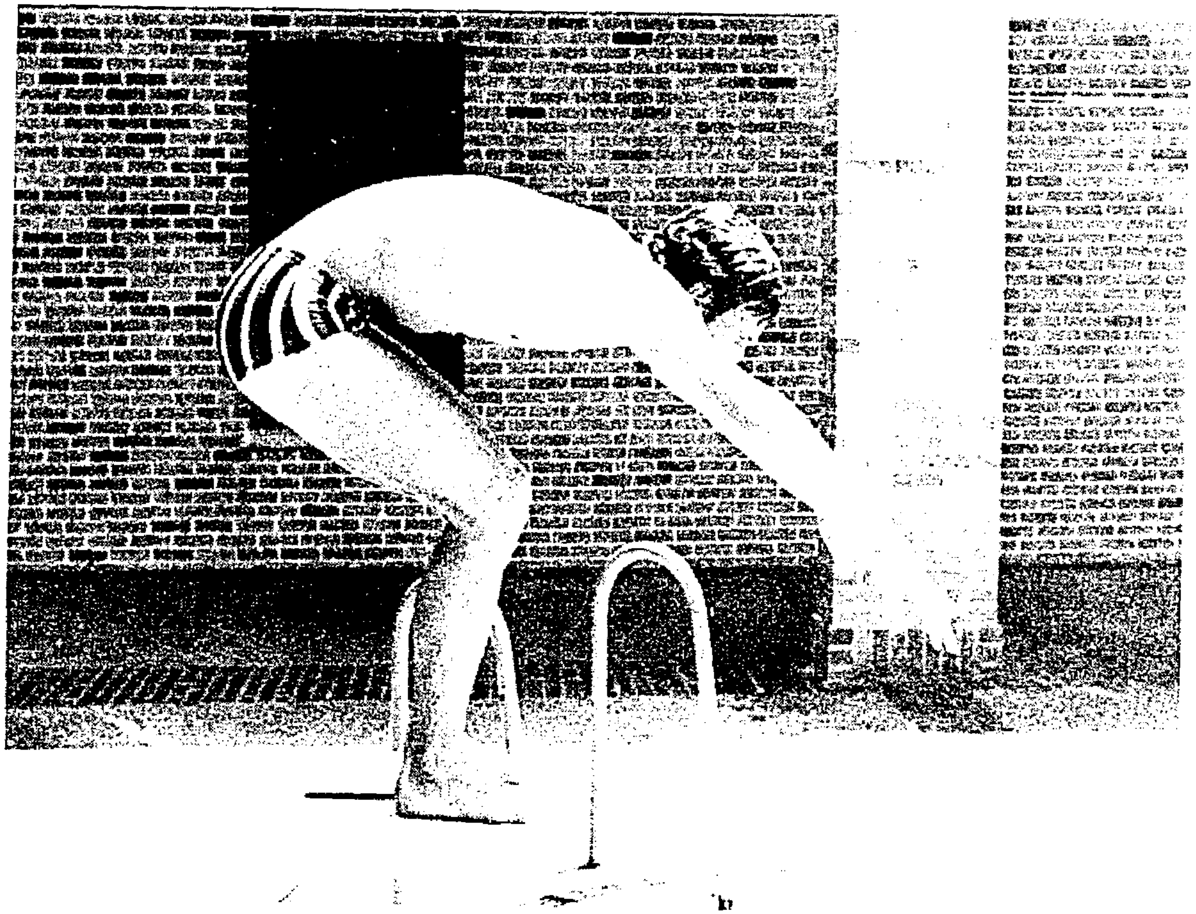

Figure 3. Pictorial Illustration of the Initial Starting Position of the Circular Arm Swing Start.

perpendicular to the lens of the camera. Photography renders a two-dimensional subject matter representation of essentially three dimensional subject matter.

Kinematic. Kinematics is that branch of physics that deals solely with motion and does not consider the forces that act upon it.

Age-group swimming. Most competitive swimming programs during the summer months come under the jurisdiction of the Amateur Athletic Union. In order to promote the sport and prompt swimmers of equal potential to compete against each other the program has been divided into age-groups. Thus, swimmers of the same sex and age are allowed to contend among their peers. In this study the age-group has been delimited to include only male swimmers fifteen through seventeen years of age. The investigator felt that swimmers of this age had had time to perfect and employ the start of their choice. Thus, they would be representative of performance at the highest level.

DELIMITATIONS OF THE STUDY

The following delimitations were imposed upon this study:

1. The seventy-five swimmers timed in this study were delimited to male swimmers of fifteen through

seventeen years of age. Each of these swimmers regularly performed one of the three starts and had been swimming for at least three years.

2. The three swimmers filmed in this study regularly performed one of the three starts and were selected from groups of twenty-five swimmers. They were chosen on the basis of exhibiting the fastest timed racing start.

3. The study was delimited to kinematic factors.

4. Human motion was studied in only the plane perpendicular to the lens of the camera.

5. The three freestyle starts employed in the study for analysis and comparison were: (1) the grab; (2) the arms back; and (3) the circular arm swing starts.

LIMITATIONS OF THE STUDY

The following limitations were noted in this study:

1. The heights of the three selected swimmers were not identical. The grab start subject was six feet tall, the arms back subject was five feet ten inches tall, and the circular arm swing subject was six feet three inches tall. As a result, the circular arm swing

subject gained an advantage over the other two when he extended himself into the race. His reach was automatically greater.

2. Braun and Fisher's[11] average segment percentage of body weight was used in the segmental method of locating the body's center of gravity. Thus, it was possible that errors were introduced when applying these measures to the three swimmers.

3. A slight perspective error was noted throughout the film analysis. Thus, errors were introduced into the calculations although they were held to a minimum.

BASIC ASSUMPTIONS

The following basic assumptions were made with regard to this study:

1. Cinematography and the analytical procedures associated with it were reliable and valid methods for collecting kinematic data.

2. The three swimmers filmed were representative of the fastest starts possible in their age-groups.

3. The three swimmers were sufficiently motivated to produce their best performance.

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[11]John M. Cooper and Ruth B. Glassow, Kinesiology (Saint Louis: The C. V. Mosby Company, 1968), p. 157.

NEED FOR THE STUDY

Most swimming coaches are desirous of knowing the fastest and easiest style of racing dive. The swimmer with the fastest and most economical start has a decided edge in a swimming race, especially one of short duration. Therefore, this study was undertaken to ascertain the fastest start. Also, an analysis and comparison of the starts revealed "how" these skills were executed and "why" they were performed in a particular manner. Knowledge of the mechanics of each start provided information with which to distinguish between correct and incorrect body movements and the cause and effect of them. Good mechanics can be taught and poor mechanics can be improved with knowledge and practice. Further, a study of this nature broadened the understanding of cinematographic procedures. Thus, other researchers in the realm of swimming and related areas would undertake studies of a similar nature to unlock the mechanical concepts of human movement.

CHAPTER II

REVIEW OF RELATED LITERATURE

INTRODUCTION

A perusal of literature related to analyzing human movement indicated that cinematography was a most useful tool. Because of its importance this investigator felt that a review of its historical development was most appropriate. Therefore, the review of related literature was divided into three sections: (1) overview of the history of cinematography and applied research related to human performance; (2) studies related to locating the center of gravity in man; and (3) studies related to the mechanical principles and descriptions of the freestyle racing start.

OVERVIEW OF THE HISTORY OF CINEMATOGRAPHY AND APPLIED RESEARCH RELATED TO HUMAN PERFORMANCE

Until the latter part of the nineteenth century, the science of analyzing human performance was restricted to the study of action in an assumed pose. Analysis of this type did not lend itself to deriving principles of motor performance. For this reason many of the principles related to human motor mechanics were of an empirical nature and were not based upon scientific principles.[1]

Some of the first work involving the analysis of movement patterns was done by Muybridge.[2] His first experiments in 1872 dealt with examining the leg movements of race horses. He wished to determine through photography whether or not a trotting horse had all four hooves off the ground at the same time. Thus began the first attempts by man to analyze motor performance through the use of the motion picture camera.

Marey,[3] experimenting with motion photography at about the same time as Muybridge, made many contributions to the analysis of performance. By analyzing the action of cats he was able to answer many of the questions of the day pertaining to rotary movement.

George Demeny, famous kinesiologist and physical educator, was a contemporary of Marey. He saw the early implications of motion photography and realized

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[1]T. K. Cureton, "Elementary Principles and Techniques of Cinematographic Analysis as Aids in Athletic Research," Research Quarterly, X (May, 1939), 3-11.

[2]Edward Muybridge, The Human Figure in Motion (Boston: Osgood and Company, 1882), pp. 21-22.

[3]T. K. Cureton, op. cit., p. 4.

its potential for physical educators and coaches. He stated that:

> . . . a laboratory of research for physical performance must take into account apparatus for measuring body movements, a laboratory of photography, cinematography, and a time recorder.[4]

These early attempts at cinematography continued throughout the first thirty years of the twentieth century. However, it was not until 1930 that many of the current methods of photography came into being. In that year Fenn[5, 6] conducted two studies of sprint running. Among other things, he devised ways of measuring the distance traveled by a runner, the time he took to do it, the center of gravity of the moving body, and the angles at which the sprinter's legs left and touched the ground. All of this information was obtained from film analysis.

Cureton made many contributions to the techniques of analyzing human performance. As an early proponent of cinematography he realized the potentialities that it held in the field of human movement analysis.

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[4]Ibid., p. 5.

[5]W. O. Fenn, "A Cinematographic Study of Sprints," Scientific Monthly, XXXII (April, 1931), 346-54.

[6]W. O. Fenn, "Frictional Kinetic Factors in the Work of Sprint Running," American Journal of Psychology, XCII (April, 1930), 583-611.

Accordingly, he noted the following objectives of the cinematographic process:

> 1. To estimate the major factors governing performance and their relative importance.
>
> 2. To derive the scientific principles of coaching, including an understanding of the physical mechanics of the skill.
>
> 3. To lay the basis for a philosophical interpretation of athletic performance based upon relatively accurate theoretical considerations subject to some degree of verification.[7]

Cureton realized that the principles of athletic performance were governed by laws of physics and that mechanical analysis of any movement could be secured from film analysis. He reviewed the then elementary principles and techniques of cinematography and stated:

> The science of mechanics is an expression of physical laws of equilibrium or movement in terms of these same fundamental or derived measurements. A mechanical analysis of any movement may be made from measurements taken from the screen.[8]

As the art of cinematography grew, many new people discovered its uses and helped devise methods and materials to improve it. One such example was

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[7] T. K. Cureton, op. cit., pp. 3-4.

[8] Ibid., p. 3.

Ruth Glassow.[9] For example, she constructed an apparatus that varied the size of projected movie frames when analyzing film. In another study Glassow[10] discussed the use of motion pictures in research. She included suggestions and methods for: (1) the clock measurement of time; (2) a known dimensional object in the field of vision; (3) computing angles; (4) identifying marks on the subjects; and (5) a stationary check mark in the background as a guide to drawing successive measurements or movements.

Francis[11] mechanically analyzed the action of six leading shot putters to determine the velocity and acceleration of successive body parts in contributing to the total performance. He did this by marking the subject on six different body parts. By measuring the distance the dots had traveled each sixth frame he was able to compute acceleration and velocity.

By the early 1950's cinematography had become a common and useful tool for analyzing human performance. Even so, better and more exacting procedures and

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[9]Ruth By Glassow, "A Convenient Apparatus for the Study of Motion Picture Films," Research Quarterly, IX (May, 1939), 41-46.

[10]Ruth B. Glassow, "Motion Picture: Their Use in Research and Practical Methods of Analysis," (unpublished paper, University of Wisconsin, April, 1940).

[11]Samuel Francis, "Mechanical Analysis of the Shot Put," Athletic Journal, XXVIII (January, 1948), 34-50.

materials were being developed to facilitate unlocking the secrets of human performance and the mechanical principles related to them.

During the past decade Stanley Plagenhoef emerged as one of the leaders in the field of cinematography. He indicated that prior to the 1960's analysis of individual performance of the whole body in motion had been lacking. He further stated that the proper techniques were now available to analyze whole body movements.[12] Plagenhoef listed seven steps utilized to gather information about the movements of force at each joint. The seven factors to be determined were:

1. Determine the length of each body segment.

2. Determine the weight of each body segment.

3. Photograph the desired motion.

4. Make a composite tracing of the total movement.

5. Locate the center of gravity and radius of gyration of each segment.

6. Determine the instantaneous, angular velocities and accelerations of each segment the desired number of times during the whole movement.

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[12]Stanley Plagenhoef, "Methods of Obtaining Kinetic Data to Analyze Human Motion," Research Quarterly, XXXVII (March, 1966), 103-104.

7. Determine the joint forces and movements of force.[13]

Noss,[14] in a critical review of the problems inherent in the photographic measurement of body angles, reminded the reader that a certain amount of error was introduced when using the motion camera. He conceded that photography was a two-dimensional subject matter representation of essentially three-dimensional subject matter. Elimination of these perspective errors would come through "tri-axial" analysis. Tri-axial analysis was a photographic research technique using three cameras to refine the critical study of human motion.

One of the latest studies, done by Prior and Cooper,[15] involved the use of powered lights to record human movement. By attaching battery powered lights to different body parts and using time exposures they were able to obtain body movement tracings on film.

A recent study completed by Purdy revealed techniques of photography that could be used in physical education. The author was interested in

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[13] Ibid.

[14] James Noss, "Control of Photographic Perspective in Motion Analysis," Journal of Health, Physical Education, and Recreation, XXXVIII (September, 1967), 81-85.

[15] Thomas Prior and John M. Cooper, "Light Tracing Used as a Tool in Analysis of Human Movement," Research Quarterly, XXXIX (October, 1967), 815-817.

providing physical educators with a basic understanding of ways that photographic material could be studied and presented. The following statements were summations of motion picture techniques that were presented in this study:

1. To arrest motion, one must reduce the image blur of film to a point where it cannot be seen upon enlargement.

2. Photography should be printed on Kodabromide Type A enlarging paper for inclusion in studies.

3. If positive prints are not needed, 8mm film may be used in analytical studies.

4. The 16mm camera becomes a good analytical tool if the filming rate of the camera is established.

5. In order to get negatives for producing selected positive prints, the shutter speed of the motion cameras must freeze the motion of the subject.

6. A variable shutter should be used if faster shutter speeds than the normal open shutter are needed.

7. To study activities which involve striking actions, it is helpful to use a cine camera with a framing rate of 200 frames per second.[16]

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[16] Kenneth Purdy, "Techniques of Photography in Physical Education Research," (unpublished Doctor's dissertation, Louisiana State University, 1969), pp. xii-xiii.

STUDIES RELATED TO FINDING THE CENTER OF GRAVITY IN HUMAN PERFORMANCE

When analyzing human performance one of the most important calculations was that of locating the center of gravity in man. Whenever man attempted to maintain balance or move his entire body he had to be cognizant of the relative position of it. As different patterns were executed the center of gravity acted as the focal point. Thus, a movement by one body segment necessitated a corresponding adjustment by another to maintain a balanced position. Many mechanical principles related to total body movement can be defined if the center of gravity is located and labeled.

Locating man's center of gravity has long been of interest to investigators. The earliest of these attempts was made by Borelli.[17] He placed a nude subject in a prone position upon a board. The board, which was balanced on a fulcrum, was moved back and forth. When the total body mass balanced he claimed to have located the subject's center of gravity.

Similar studies using nude subjects and frozen cadavers have been used to locate the center of gravity. In each instance, however, the bodies were in an

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[17]John M. Cooper and Ruth B. Glassow, Kinesiology (Saint Louis: The C. V. Mosby Company, 1968), pp. 125-129.

extended stationary position. Because of the nature of this study the above mentioned methods of locating the center of gravity were neither considered nor further reviewed. Instead, two of the most common methods of locating the center of gravity in a moving body were reviewed. The two methods of locating the center of gravity in human movement were: (1) the scale method, and (2) the segmental method.

Scale Method[18]

The scale method has been successfully employed by researchers in locating the center of gravity in man. The mechanics for establishing it were simple and did not require much time or effort. However, additional photography other than the original filming had to be employed and utilized when locating the center of gravity.

Basically, the procedure consisted of placing a subject on a rectangular piece of plywood of known dimensions and weight. Each corner of the board was supported by scales. The center of gravity of a subject from a selected frame was found by centering the subject on his side with the hip joint as focal point. He was placed in the same position as seen in

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[18] *Ibid.*, pp. 184-188.

the film. After assuming the selected position on the plywood an overhead photograph was taken. By computing the sums of the scale readings to the right and those to the left the center of gravity was measured in the sagittal plane. The scale readings at the top and bottom were used to determine the position of the center of gravity in the transverse plane. These scale readings indicated the distance and direction that the assumed center of gravity would have to be moved.

Segmental Method[19]

Cooper and Glassow have stated:

> In the discussion of the center of gravity of a human body in motion, it was stated that the center of gravity could be located if the center of gravity of the various body segments were located with reference to each other.[20]

Therefore, the following information was needed to locate the body's center of gravity:

1. The percentage of the total body weight of each segment.

2. The location of the center of gravity of each segment.

3. The horizontal distance of each center of gravity from a vertical line.

4. The vertical distance of each center of gravity from a horizontal line.[21]

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[19] *Ibid.*, pp. 160-164.

[20] *Ibid.*, p. 160.

[21] *Ibid.*

Braune and Fisher[22] performed some of the first work on determining the percentage of the total body weight for each segment. Their calculations are shown in Table 1 and were used in this study.

Table 1

Segment Percentage of Body Weight

Body Segment	Percentage Body Weight
Head and neck	7.06
Trunk	42.70
Upper arms	6.72
Thighs	23.16
Forearms and hands	6.24
Legs and feet	14.12
Total	100.00

After locating the center of gravity of each body segment Braune and Fisher[23] expressed its location in terms of a percent of the distance from one body reference point to the next and along the respective

[22] Ibid., p. 157.

[23] Ibid., p. 159.

long axis. The center of gravity of the head and neck was estimated as the vertical distance from the seventh cervical vertebra to the tragus of the ear when the head was erect. The center of gravity of the trunk was located 45.1 percent of the distance from the greater trochanter of the femur to the head of the humerus. The center of gravity of the upper arm was located 44.4 percent of the distance from the greater tuberosity of the humerus to the elbow. The center of gravity of the thigh was located 44.4 percent of the distance from the greater trochanter of the femur to the knee joint. The center of gravity of the forearm and hand was located 66.6 percent of the distance from the finger tips to the elbow. The center of gravity of the lower leg and foot was located 60.6 percent of the distance from the knee to the heel. Refer to Figure 4 on page 31 for the approximately location of the body segment reference points.

After determining the percentage of the total body weight for each segment and locating the center of gravity of each segment, Cooper and Glassow stated:

> With these estimations of the percentage weights and of the location of the center of gravity of segments the center of gravity of the total body can be approximated if the relative position of segments is known. These can be determined from film.[24]

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[24]*Ibid.*, p. 160.

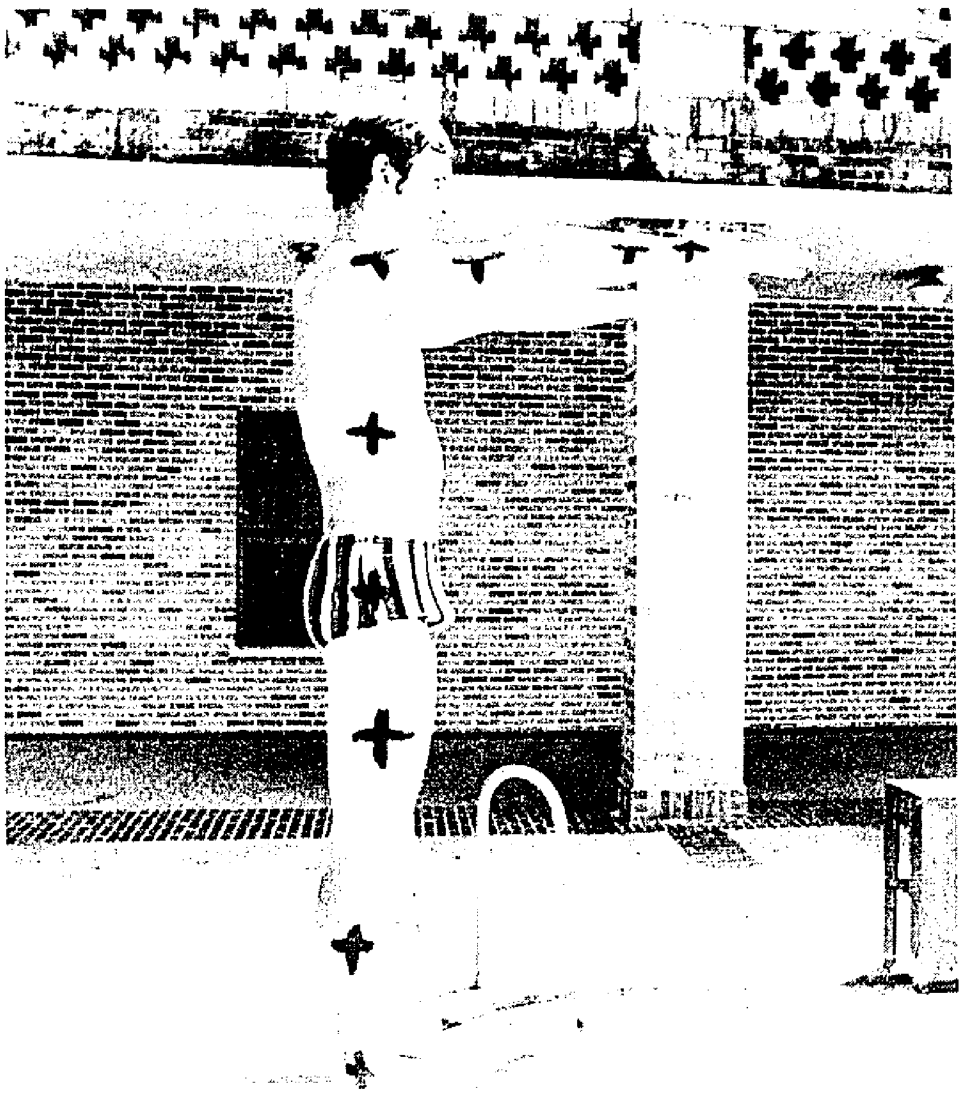

Figure 4. Pictorial Illustration of Body Reference Points Used in Computing the Body's Center of Gravity.

By placing a horizontal and vertical line through the projected pelvic region of each subject the center of gravity of the total body was calculated. The distance of each segment center of gravity from the horizontal line was measured in millimeters. The effect of gravitational force on each segment was equal to the measured distance times the percentage of weight. The difference between the sums of those products above the horizontal line and those below it denoted whether the line marked the true plane of the body's center of mass and, if not, the direction and amount which it was moved. If the difference between the sums was positive the line was moved upward a number of millimeters indicated by the difference. Conversely, if the difference was negative the line was moved down. The same procedure was used with reference to the vertical line. Refer to the appendices of this dissertation for the calculations used in computing each body's center of gravity.

STUDIES RELATED TO MECHANICAL PRINCIPLES AND DESCRIPTIONS OF FREESTYLE RACING STARTS

Literature related to competitive swimming does not abound with scientific studies regarding the comparison of one start to others. Generally, the authors of swimming articles write on the type of start that they prefer and then render an empirical analysis and description of it. Therefore, many of the questions regarding the similarities and dissimilarities of different starts are left unresolved and which is superior, if any. For clarity of presentation and understanding this section was sub-divided into four areas. The four areas were: (1) early studies of freestyle racing start; (2) grab start; (3) arms back start; and (4) circular arm swing start.

Early Studies of Freestyle Racing Starts

No one really knows what style of racing dive was first used. Like so many other aspects of swimming, it just appeared to have happened. Barnes[25] rendered one of the first modern written accounts of the free-style start. He stated that the dive resembled the standing broad jump. Like the broad jump, the aim of the racing start was to attain maximum horizontal distance by the athlete. In order to attain maximum horizontal distance the swimmer had to propel himself upward and outward. Barnes indicated that at the start

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[25]Gerald Barnes, Swimming and Diving (New York: Charles Scribner's Sons, 1922), pp. 39-43.

of the dive the swimmer had to bend forward at the waist and rest his hands upon the knees. Upon hearing the starting command, the swimmer's hands and arms rotated vigorously clockwise, then counterclockwise as done in the standing broad jump. Of course, the difference between the two was the head first entry into the water by the swimmer as opposed to the feet first landing on the ground by the jumper.

Daviess[26] was one of the early women experts on swimming. She advocated a combined arms forward and arms back start. The swimmer assumed the ready position with arms extended and parallel to the water surface. The subject further assumed the ready position by bending slightly forward at the waist and knees. As soon as the swimmer wished to initiate his start he simply lowered his arms and rotated them backwards. This action moved the subject's center of gravity past the base of support. As the body left the blocks the arms returned to an extended overhead position.

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[26] Grace B. Daviess, Swimming (Philadelphia: Lea and Febiger, 1932), pp. 112-114.

Tuttle and Morehouse,[27, 28] conducted two experiments involving the use of starting blocks and optimum time for holding swimmers to their marks. The first study dealt with the use of starting blocks. Prior to that time the race was initiated from the pool deck. After raising the starting platform to different heights they found the height of twenty-four to thirty inches to be the most nearly ideal. Heights up to twenty-four inches did not allow the swimmer to project himself very far into the race. Heights over thirty inches resulted in too obtuse an angle of water entry and too deep an immersion by the swimmer. The two researchers concluded that a raised height of thirty inches was ideal. Their second study was an attempt to find the optimum time for holding swimmers to their marks. They wished to determine whether any particular time lapse between the command to start and the firing of the gun would have any effect on the swimmer's ability to leave the block. No significant differences were found among the time intervals of 1.6, 1.8, or 2.2 seconds. They concluded that a time lapse interval of two seconds was ideal. Also, it took

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[27]W. W. Tuttle and L. E. Morehouse, "Use of Starting Blocks," Research Quarterly, X (March, 1939), 103-7.

[28]W. W. Tuttle and L. E. Morehouse, "Starting and Holding Marks," Research Quarterly, XI (March, 1940), 73-9.

the swimmer an average of .988 seconds to leave the starting block from the time the gun was fired until the swimmer's feet left the block.

From time to time new innovations were added to the basic pattern of the racing start in hopes that it might give an added benefit to the swimmer. Smith,[29] for example, implied that the "Coiled Spring Racing Dive" was superior to the regular arms back or circular arm swing start in two ways. First, the start followed the dynamic explosive action pattern of a released coiled spring and second, the restricted arm windup allowed for better body control throughout the start. Basically the ready position assumed by the swimmer was the same as the other starts except that the arms were held against the stomach. The start was executed by the subject simply reaching outward as he left the starting block.

One of the most scientific and knowledgeable studies ever done on the freestyle racing dive was conducted by Heusner.[30] The purpose of his research was to determine the optimum angle of take-off for a

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[29] Alton Smith, "The Coiled Spring Racing Dive," Athletic Journal, XXXVIII (May, 1958), 51-53.

[30] William W. Heusner, "Theoretical Specifications for the Racing Dive: Optimum Angle of Take-off," Research Quarterly, XXX (March, 1959), 25-33.

swimmer leaving the starting blocks and to construct a mathematical equation that would estimate the true time needed for a twenty-five yard sprint. He calculated, among other things, that a projected upward take-off of thirteen degrees from the horizontal was ideal. Without going into the procedures he validated his findings by the cinematographic method.

By the late 1950's more and more attention was being placed upon the angle of take-off. Heffner[31] reasoned that there were three possible angles of take-off available to the swimmer. The first take-off angle was in an upward trajectory. The second was in a horizontal or straight line. The third was a take-off angle from which the swimmer literally dove down and into the water. He concluded that the second or horizontal trajectory was the best. Heffner further stated that an upward trajectory left the swimmer in an arched position from which he would not properly enter the water. A downward trajectory caused the swimmer to enter the water too soon. On the other hand, a horizontal trajectory projected the swimmer a good distance into the race and allowed proper body alignment for water entry. In the same article Heffner

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[31]Fred Heffner, "The Swimming Start," Athletic Journal, XXXIX (May, 1959), 18.

alleged that during the ready state the subject should be as relaxed as possible. He felt that the arms and head should hang loosely; otherwise, they only tightened the swimmer, thus impeding his start.

Grab Start

During the past decade the arms back and circular arm swing starts have continued being the two most popular methods of initiating swimming races. However, a new style called the "grab start" has gained popularity throughout the country.

This author, while swimming coach at Louisiana State University from September, 1968 until August, 1970, had the opportunity of watching top collegiate swimmers perform. Although the grab start was not as widely used as the other two, the author has seen a growing trend in its favor. On January 29, 1969 at the University of Tennessee this author saw Dave Edgar use the grab start. Edgar had been the last one off the starting blocks in previous races until he employed the grab start in which case he was first. Since that time Edgar[32] has become known as the fastest swimmer in the world. Other

[32]"They Went So Fast It Made Your Head Swim," Swimming World, XII (April, 1971), 7.

collegiate and AAU swimmers have used the grab start with equal effectiveness.

Gambril[33] declared that fast or slow starters were born. If a swimmer had slow reactions to the starting command, he should experiment with the grab start. When utilizing the grab start Gambril feels that the slow starter can cut down on the lead of other swimmers by getting into the water sooner. Thus, a swimmer with poor reaction time could theoretically use the grab start to enter the water quicker than a fast starter although he does not propel himself as far out.

Basically there are two variations to the grab start. The type of starting block used will in many instances determine the style used. In general, however, the starts are the same except for the placement of the hands. In the first style the swimmer places his feet shoulder-width apart on the leading edge of the starting block and crouches low enough so that he can grab the front of the blocks. The swimmer's body weight is forward so that a slight push back against the starting block with the hands will precipitate his fall foward. As he leaves the starting blocks the arms are swung

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[33]Donald L. Gambril, Swimming (Palisades: Goodyear Publishing Company, 1969), pp. 53-58.

counterclockwise to an extended overhead position. In the second variation the swimmer reaches back and grabs the sides of the starting block. He then leans forward as far as possible and positions his center of gravity beyond the leading edge of the starting block. To initiate his start the swimmer simply releases his hold, extends himself, and falls toward the water due to the pull of gravity. When performing both grab starts the swimmer's trajectory is lower than the other two and the swimmer enters the water sooner.

Arms Back Start

Lindberg[34] indicated that each person must employ his own style of start. However, the main ingredients to look for were strong leg and arm thrusts. For this reason he believed that the arms back dive was the most advantageous. The forceful transfer of momentum generated by the forward thrust of the arms to the total body momentum made the arms back dive ideal.

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[34]Russell Lindberg, "Racing Start," Athletic Journal, XX (April, 1939), 16-19.

Kiputh,[35] writing at about the same time as Lindberg, also advocated the arms back start. He, too, believed that the transfer of momentum gained through the forceful forward arm swing made the arms back start the most advantageous dive. In addition, Kiputh stated that the swimmer could gain maximum horizontal distance into the race by using this dive.

Bunn[36] experimented with the racing start and indicated the arms back style was superior to others. He maintained that the start consisted of upsetting the body's equilibrium. This was best done by positioning the toes over the edge of the starting block, placing the body weight on the balls of the feet, and otherwise assuming the arms back starting position. Initial movement was accomplished by rocking back on the heels and further hyperextending the arms at the shoulder joint. The resultant action moved the center of gravity forward outside the base of support and started the body falling toward the water. As the swimmer left the starting block he extended himself and rotated his extended arms to an overhead position. The clockwise

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[35] Robert Kiputh, Swimming (New York: A. S. Barnes and Company, 1942), pp. 63-66.

[36] John W. Bunn, Scientific Principles of Coaching (Englewood Cliffs: Prentice-Hall, 1959), pp. 185-186.

rotation of the swimmer as he left the starting block positioned the body for a head first entry into the water.

Carlile,[37] considered one of the outstanding foreign swimming experts, has maintained that the arms back start was the best. He stated that the secret to the racing start was the immediate backward swing of the arms which caused the body to thrust forward. His reasoning was that for every action there was an equal and opposite reaction. Thus, the backward thrust of the arms propelled the body forward.

Armbruster[38] described both the arms back and circular arm swing starts but indicated a preference for the former. He advocated the arms back start because of the swimmer's ability to maintain slight upward movement of the arms as he assumed the ready position. This slight but imperceptible movement by the swimmer allowed him to leave the starting blocks sooner. Armbruster also indicated that the angle of take-off should be as nearly horizontal as possible. A horizontal trajectory allowed the swimmer to dive farther out into the water than would a trajectory below the horizontal.

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[37] Forbes Carlile, Forbes Carlile on Swimming (London: Pelham Books, 1963), p. 152.

[38] David A. Armbruster and others, Swimming and Diving (Saint Louis: C. V. Mosby Company, 1968), pp. 46-60.

Gambril[39] indicated that he preferred a modified arms back start to the others. His modified start was basically the same as Armbruster's. In other words, Gambril believed that the swimmer should approach the ready position with the arms hanging loosely down. As he waited for the command to start the swimmer's arms should rotate slightly clockwise. Thus, an object in motion tended to stay in motion.

Circular Arm Swing Start

Mowerson[40] studied the circular arm swing and arms back racing styles of nine collegiate swimmers. In general he found the circular arm swing start faster. However, he recorded time only from the gun start until the feet left the block. The conclusion based on his study was that it would be best to teach a beginner swimmer the circular arm swing start. However, he further implied that a competitive swimmer who was consistently fast in the arms back start should not be encouraged to change.

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[39] Gambril, op. cit., p. 53.

[40] G. R. Mowerson, "Comparison of 2 Methods of Performing the Racing Start in Competitive Swimming," Swimming World, V (February, 1964), 4-5.

Clark,[41] a triple gold medal winner in the 1964 Olympics, was considered at that time the premier freestyle swimmer in the world. He used the circular arm swing start and found it most advantageous. Clark further revealed that he tried to leave the starting block in as nearly a horizontal take-off position as possible. He did not try to gain height in the dive or enter the water too soon by diving downward. He felt that the greatest horizontal distance gained in the start was from a horizontal take-off.

Armbruster,[42] in addition to describing the arms back start, mentioned the circular arm swing start as a variation in style. He indicated that the circular arm swing start was used to move the swimmer's center of gravity forward with greater rapidity than the other starts. The forward movement of the center of gravity was accomplished by knee and hip flexion aided by the counterclockwise rotation of the arms. He also indicated that the circular arm swing start was best suited for relay starts. The reasoning behind this belief was that the starting swimmer could aim

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[41] Steve Clark, Competitive Swimming As I See It (North Hollywood: Swimming World, 1967), pp. 45-50.

[42] Armbruster, *op. cit.*, p. 58.

down his outstretched arms at his incoming companion and best judge when to initiate his start.

Maglischo[43] reported that the speed traveled during the first fifteen feet of a race was not significantly faster between the circular arm swing and arms back start. However, he indicated that a trend was noticed in favor of using the circular arm swing start. Timing the first fifteen feet of the race was done by using the Dekan Human Performance Analyzer.

Counsilman,[44] recognized by many as the leading authority on swimming, has advocated the circular arm swing start. He stated that the most common misconception about the start concerned the right and wrong ways of performing the arm movements. He further indicated that most swimmers tried to keep their arm swing to a minimum. They had been taught that the arm swing should be directly back and then forward. The implied logic behind this type of action was that the backward swing of the arms moved the swimmer's center of gravity forward and precipitated his fall toward

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[43]Ernest Maglischo, "Comparison of Three Racing Starts Used in Competitive Swimming," Research Quarterly, XXXIX (October, 1968), 604-609.

[44]James E. Counsilman, The Science of Swimming (Englewood Cliffs: Prentice-Hall, 1968), pp. 133-142.

the water. Counsilman maintained that the flaw in this reasoning was that the center of gravity of the total body remained at the same point. He stated: "A person could stand on the edge of the Empire State Building doing this motion and never fall off."[45]

In defense of the circular arm swing start, Counsilman stated:

> The arms should make a circular swinging motion before the swimmer leaves the starting block. As the arms make the circle, they accelerate and build up tremendous angular velocity. When they are stopped, their momentum is transfered to the body and pulls it in the direction the arms were going at the time they were stopped.[46]

In conclusion, Counsilman contended that the contraction of the tibialis anterior muscle and relaxation of the calf muscle caused the center of gravity to move forward.

Torney[47] indicated that he favored the circular arm swing start over other methods of starting. He contended that the swimmer moved his body forward by relaxing the muscles at the waist, hips, knees, and ankles. As the swimmer fell, he simply rotated off the starting block. His forward momentum was aided by the circular swinging motion of the arms.

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[45] Ibid., p. 133.

[46] Ibid., p. 134.

[47] John A. Torney and Robert D. Clayton, Aquatic Instruction, Coaching, and Management (Minneapolis: Burgess Publishing Company, 1970), pp. 261-262.

SUMMARY OF RELATED LITERATURE

The first section of this chapter presented an introduction to the review of related literature. For clarity of organization and presentation the chapter was divided into three other sections: (1) overview of the history of cinematography and applied research related to human performance; (2) studies related to locating the center of gravity in man; and (3) studies related to the mechanical principles and descriptions of the freestyle racing start.

The second section was concerned with the historical development of cinematography. Many of the methods and materials used in this study were reviewed in this section.

The third section afforded a review of the methods of locating the center of gravity in man. Methods of locating the center of gravity in man while in an extended, stationary position, and one in which movement takes place was presented.

The fourth section was sub-divided into four subsections: (1) early studies of freestyle racing starts; (2) grab start; (3) arms back start; and (4) circular arm swing start. Seven studies were reviewed that described the evolution of the freestyle racing start.

Two studies were presented that reviewed information concerning the grab start. Because of its relative newness few formal articles have been written about it. Most of its merits and principles have been passed by word of mouth. Six studies were reviewed in which the authors indicated a preference for the arms back start. An additional six studies indicated that the authors favored the circular arm swing start.

In conclusion, the following thoughts were expressed throughout the review of related literature:

1. That the freestyle start evolved from the basic principles underlying the standing broad jump.

2. That the earliest modern freestyle start was a variation of the arms back start.

3. That initiating movement of the subject's center of gravity as soon as possible was of paramount importance.

4. That the angle of take-off should be as nearly horizontal as possible.

5. That the arms back start was faster than the circular arm swing start but did not develop as much arm momentum as did the circular arm swing start.

6. That swimmers with slow reaction time should try the grab start.

CHAPTER III

DESCRIPTION OF PROCEDURES

INTRODUCTION

The purpose of this investigation was to determine which of three distinct freestyle racing starts was the fastest and to mechanically describe, analyze, and compare the component parts of each one. Ten subpurposes were postulated in order to extract qualities indicative of championship performance.

Seventy-five swimmers from Texas, Mississippi, and Louisiana volunteered to serve as subjects for the study. Three groups of twenty-five swimmers were timed for the first fourteen feet of the start and race. A Dekan Human Performance Analyzer was utilized to collect the data. Analysis of variance was the statistical method used to determine whether differences existed among the three starts.

The swimmer exhibiting the fastest start in each group was selected for film analysis. In light of the purposes of this study and the nature of the skill involved, this investigator used cinematography as the method of securing the raw data.

A comparative and descriptive analysis of the three starts was compiled from selected film frames every tenth of a second. In order to present the clearest rendition of skill execution, stick figures were compiled in addition to sequence photos. They were composed of a connecting system of link lines drawn on the lateral surface of the lower leg, thigh, trunk, upper arm, forearm, and head. As the subject executed the skill gross movement characteristics were revealed through the progressive sequence drawings.

MATERIALS UTILIZED IN THE STUDY

The following equipment and supplies were needed to gather and analyze the pertinent data:

Dekan human performance analyzer. The Dekan Human Performance Analyzer was employed to collect and record the time utilized by a swimmer to traverse the first fourteen feet of a start and race. It was calibrated at the Louisiana State University Physics Department for accuracy. Refer to Section V of Chapter III on page 54 for a description of the timing procedure used.

Motion picture camera. The camera used for recording the racing dives was a Bolex H-16 Rex model. A Kern-Pillard wide angle lens was mounted on the camera to provide the necessary depth of field viewing. The variable shutter was pre-set at one-half opening to insure proper exposure time. In addition, the camera was pre-set to record at 64 frames per minute. Refer to Section VIII of Chapter III on page 59 for a description of the filming procedure used.

Film. Black and white 16mm Kodak Tri-X Reversal film 7278 was used to record the raw data. After processing it was secured for analysis.

Film reader. An Eastman Kodak Recordak film reader, model MPE-1, was used as a projection device for analyzing the processed film. After placing the film in the reader and manually selecting the desired frame, a projected eight by ten inch image of each film frame was rendered. All calculations were derived from the projected image.

Starting block. NCAA and AAU rules specified that all swimming starts must be initiated from a standard racing platform. The starting block must be thirty inches above the water and parallel to it. Also, the leading edge must be directly over the edge of the pool.

Timing device. A Lafayette 1/100 second hand sweep clock, model number 5661ADW, was placed in the field of view to record time. It was calibrated at the Louisiana State University Physics Department for accuracy. The clock served as a calibration device for establishing filming rate. Refer to sub-heading "Camera Calibration" in Section VIII of Chapter III on page 61 for a description of the timing procedure used.

SELECTION OF SUBJECTS FOR TIMING AND THEIR QUALIFICATIONS

In order to determine which of the three free-style racing starts was the fastest, seventy-five swimmers were selected and timed. The swimmers were divided into three groups with each subject executing his preferred racing start. Those swimmers performing similar starts were placed in the same group.

During June, 1970, this investigator traveled to four AAU sanctioned swimming meets to collect data. The four meets were:

1. Baton Rouge YMCA Invitational, Baton Rouge, Louisiana, June 5-6, 1970.

2. Greenwood Invitational, Greenwood, Mississippi, June 10, 1970.

3. Alexandria Invitational, Alexandria, Louisiana, June 19-20, 1970.

4. Metairie YMCA Invitational, Metairie, Louisiana, June 26, 1970.

Prior to the start of each meet this investigator solicited the aid of any swimmer that qualified as a subject for this study. The qualifications were:

1. That the swimmer was male.

2. That the swimmer was between fifteen and seventeen years of age and had not participated on a collegiate swimming team.

3. That the swimmer had had at least three consecutive years of age group swimming prior to this study.

4. That the swimmer used one of the three starts regularly.

SELECTION OF SUBJECTS FOR FILMING

The swimmer in each group exhibiting the fastest start was selected for filming. It was assumed that the subject with the fastest start performed the dive best in terms of mechanical efficiency. A comparison of the starting times indicated that Art Plemmons, hereafter referred to as Subject A, performed the fastest grab start; that Bruce Redman, hereafter referred to as Subject B, performed the fastest arms back start; and that John Russell, hereafter referred to as Subject C, performed the fastest circular arm swing start. Refer to Appendix A for the starting times for the seventy-five swimmers. Filming of the three subjects took place at the Louisiana State University swimming pool in Baton Rouge, Louisiana on August 11, 1970.

TIMING PROCEDURES

At each swimmer's convenience and after having ensured that he qualified for the study this investigator collected starting times. This was accomplished by means of the Dekan Human Performance Analyzer.

The analyzer was placed on the pool deck immediately to the left of the starting block. One end of a fourteen foot piece of string was clipped to the drawstring of the swimmer's suit. It was attached just above the buttocks by means of an alligator clip. The other end was attached to a wood wedge which was inserted into a switch on top of the analyzer. The switch was an accessory device that deactivated the timer when the wedge was removed. After the command of "Swimmers, take your marks!" the delayed time starter was depressed. The activated analyzer emitted a buzzing sound at which time the subject executed the appropriate dive as fast and accurately as possible. As the swimmer left the starting block the coiled string unwound. When the swimmer's hips had passed fourteen feet into the race, the wedge was extracted from the analyzer. This deactivated the timing device which had been going since the start of the dive or when the analyzer had emitted the buzzing sound. Refer to Figure 5 on page 56 for the recording procedures utilizing the analyzer.

Prior to each timing session the subject was requested to perform two practice starts. If, by visual observation, the subject did not execute a representative start, he was disqualified as a participant. Upon completion of the practice dives the subject was instructed to perform three timed dives. His best time was recorded.

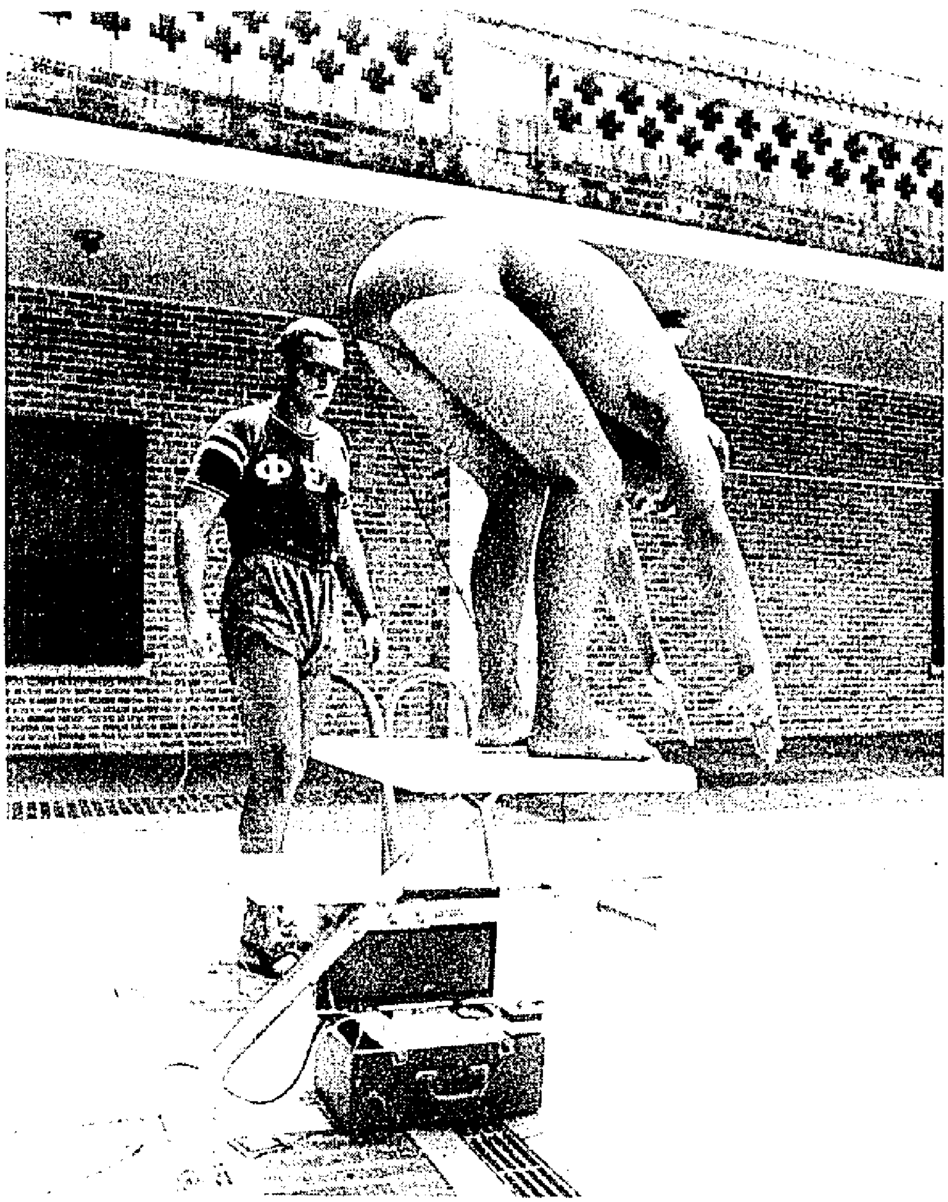

Figure 5. Pictorial Illustration Revealing the Dekan Human Performance Analyzer Used to Time the First Fourteen Feet of a Race.

STATISTICAL PROCEDURES

A two-part analysis of variance was utilized to determine whether one style of racing dive was faster than theother two. To do so, seventy-five swimmers were tested for the length of time it took each one to travel fourteen feet from the start. The subjects were divided into three groups according to the style of start they employed. If significant differences existed, an orthogonal comparison would be employed to determine where the differences occurred.

In treating the data, however, time was not used. Instead, the time required for each dive was converted into feet per second and employed in the statistical procedures. This technique was followed because time is a reciprocal in the formula $V = \frac{D}{t}$.

BODY REFERENCE POINTS

Due to the nature of this study two types of body reference points were utilized. In each instance, however, the marks were painted on the subject with "black glare" a jelly-like substance normally placed under the eyes of athletes to reduce the glare from the sun. It showed plainly on film and did not wash away as the subject dove into the water. The two types of reference points were segmental and wrist trajectory reference points.

Segmental Reference Points

In order to determine the subject's center of gravity by the segmental method the centers of gravity of the body parts were labeled. Two inch crosses of pigment were painted on the lateral surface of each body part. The following body reference parts were labeled: (1) head and neck; (2) upper arm; (3) forearm and hand; (4) trunk; (5) thigh; and (6) lower leg and foot. Refer to Figure 4 on page 31 for a pictorial illustration of the segmental reference points and sub-heading "Segmental Method" in Chapter II on page 28 for the approximate location.

Wrist Trajectory Reference Point

Two inch crosses were painted on the styloid of the ulna to serve as wrist trajectory reference points. This was done to facilitate the comparative description among the three distinct arm styles displayed in the starts. Refer to Figure 4 on page 31 for a pictorial illustration of the wrist trajectory reference point.

FILMING PROCEDURES

Certain cinematographic procedures and controls were followed to insure proper collection of data. The subsequent measures were utilized to gather accurate information.

Projected Field of View Reference Point

After leveling the top of the starting block to procure a reliable starting point, an eighteen inch "T" mark was placed in the field of view to provide a vertical and horizontal reference point. This point of reference was used during film analysis to afford the investigator a means of centering each film frame.

Reduction Factor

True life sizes and those on film were not the same. Bunn[1] stated: "The size of the image varies directly as the distance from the lens to the screen." He further revealed that if some known dimension appeared on the film corrections could be easily made.

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[1]John W. Bunn, Scientific Principles of Coaching (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1959), p. 278.

For this reason a ten inch strip of black tape was placed on the side of the starting platform and in the same plane of movement as the subject. Therefore, due to the diminutive measures employed in this study a "divider technique" was used to scale and record distances. The divider technique utilizes a proportional compass to mark off and compare the scaled measures against known linear distances in the field of view.

Camera Placement

The camera (using the center of the lens as reference point) was mounted on a stationary leveled tripod thirty-six vertical inches from the water level, sixty horizontal inches from the leading edge of the starting block, and fifty-two perpendicular feet from the plane of movement in which the action transpired. When photographing linear movement of the body, Bunn[2] stated that the perspective error would be reduced if the camera was placed as far from the subject as possible.

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[2] Ibid., p. 280.

Camera Calibration

The camera was continually calibrated throughout the filming by means of a 1/100 second hand sweep clock. It was stationed five feet in front of the camera lens in such a manner that the face of the clock appeared in only the lower left quadrant field of view. Therefore, during film analysis the investigator merely read the clock to know the filming time.

Filming Procedures

Prior to each filming sequence, a light reading was taken to properly set the lens F-stop. Also, the camera was rewound to its maximum tension and checked for proper working conditions. To record all possible subject movement the camera was started approximately two seconds before each performance and continued until the body was completely submerged in the water.

Subject Order

Each subject executed his preferred dive three times. In order not to fatigue the performers or have one swimmer influence the others, a counter-balanced order of diving was used. Refer to Table 2 for the counter-balanced subject order of diving.

Table 2

Counter-balanced Subject Order of Diving

Subject	Dive 1	Dive 2	Dive 3
A - Grab Start	1	3	2
B - Arms Back Start	2	1	3
C - Circular Arm Swing Start	3	2	1

CINEMATOGRAPHIC ANALYSIS AND DESCRIPTIVE PROCEDURES

Questions related to the second major purpose of this study and its related sub-problems were answered through the following cinematographic techniques.

Cinematographic Descriptive Analysis

A descriptive analysis of each dive was compiled from selected film frames every tenth of a second. In order to present the clearest rendition of skill execution, stick figures were compiled in addition to the sequence photos. They were composed of a connecting system of link lines drawn on the lateral surface of the lower leg, thigh, trunk, upper arm, forearm, and head. The lines connected the ankle, knee, hip, shoulder, elbow and wrist joints. As the subject executed the dive, gross body movements were revealed through the progressive sequence drawings.

Composite Graphs

A comparative trajectory of the arms was established every tenth of a second by plotting the movement patterns of the styloid of the ulna directly from the recordak film reader. The subject's centers of gravity were also computed every tenth of a second. Instead of taking the raw data directly from the selected frames the investigator had to compute the centers of gravity by the segmental method. Refer to sub-heading "Segmental Method" in Chapter II on page 28 for an explanation of this procedure.

Mathematical Computations

The following formulae and procedures were used to ascertain factors related to the sub-purposes of the study as well as validifying the projected paths of the centers of gravity:

Angle of take-off. The angle of take-off referred to that angle at which the body's center of gravity was projected toward the water. It was found by drawing a line parallel to the starting block and through the center of gravity as the body left the starting block. A second line was subsequently drawn through the above mentioned center of gravity and the center of gravity two film frames after the feet had left the block. The angle formed at the junction of these two lines revealed the take-off angle of the body.

Take-off velocity.[3] The take-off velocity of the body was measured relative to the center of gravity and incorporated the centers of gravity mentioned in the preceding subdivision. The vector quantity was found by utilizing the following formula:

$$V = \frac{D}{t}$$

Where: V = velocity in feet/second (unknown).

D = distance in feet scaled from the recordak (known).

t = elapsed time during which the measure was taken. It was taken directly from the film (known).

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[3] Ibid., p. 23.

Validation of center of gravity trajectory. As each subject left the starting block his center of gravity traversed the path of a projectile. The laws governing this phenomenon indicated that the trajectory must describe a parabola. Therefore, the center of gravity began moving in a horizontal and vertical direction corresponding to the laws of physics. The starting reference point from which the vertical and horizontal measures were taken was located at the junction of the subject's center of gravity as he began airborne flight. The terminating reference point from which the vertical and horizontal measures were taken was located at the junction of the subject's center of gravity as his hands entered the water. The theoretical and computed components of the trajectory were compared for validity. The computed vertical and horizontal components were scaled directly from the film. The theoretical vertical and horizontal components were revealed by the following formulae:[4, 5]

1. $R = V_o \cos \Theta\, t$

   Where: R = Range or horizontal distance that center of gravity traversed.

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[4]Francis W. Sears and Mark Zemansky, University Physics (Reading: Addison-Wesley Publishing Company, Inc., 1970), p. 78.

[5]Ibid.

V_o = take-off velocity of center of gravity.

Θ = angle of take-off of center of gravity.

t = time of flight of center of gravity.

2. $h = 1/2\ gt^2 + V_o \sin \Theta\ t$

Where: h = vertical height that center of gravity dropped.

1/2 = a constant in the formula.

g = 32 feet/sec/sec or the pull of gravity.

t = time of drop of center of gravity.

V_o = take-off velocity of center of gravity.

Θ = angle of take-off of center of gravity.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

INTRODUCTION

Seventy-five male age-group swimmers were timed during the first fourteen feet of a freestyle start and race. They were divided into three equal groups representing three distinct styles of starts. An analysis of variance was employed to determine whether significant differences of speed existed among the three starts.

In addition, a descriptive analysis of each dive was presented. The data obtained for each analysis was secured directly from film taken of the fastest subject in each group. The purpose of the description was to facilitate a more accurate understanding of the mechanics employed by each swimmer as he executed the skill. Further, a descriptive comparison of each dive was rendered. This was done to present the similarities and dissimilarities noted among selected component parts of each dive. In order to successfully describe and compare the dives certain established cinematographic procedures were followed.

STATISTICAL RESULTS

The times needed by each of three groups of twenty-five swimmers to reach a point fourteen feet into a race are presented in Appendix A. During the treatment of the data times in seconds were converted to feet per second. This was done because time is a reciprocal of velocity and cannot be compared. Instead, velocity was used. Refer to Table 3 for the conversion of time to velocity. A perusal of Table 3 revealed that the grab start subjects had a high velocity of 9.15 feet/second, a low velocity of 6.33 feet/second, and a mean velocity of 8.31 feet/second; that the arms back subjects had a high velocity of 9.10 feet/second, a low velocity of 6.80 feet/second, and a mean velocity of 7.91 feet/second; and that the circular arm swing subjects had a high velocity of 8.80 feet/second, a low velocity of 6.66 feet/second, and a mean velocity of 8.14 feet/second. A summary of the analysis of

Table 3

Velocity in Feet Per Second for the First Fourteen Feet of a Race for Three Groups of Freestyle Swimmers Performing the Grab, Arms Back and Circular Arm Swing Starts

	Grab Start		Circular Arm Start		Arms Back Start	
1.	C.M.	9.10	M.M.	8.09	K.R.	7.25
2.	G.M.	8.14	H.N.	7.77	B.M.	7.77
3.	A.P.	9.15	P.L.	8.29	K.R.	7.32
4.	B.S.	9.03	B.W.	8.33	R.H.	7.60
5.	B.J.	8.64	R.G.	8.53	W.N.	7.40
6.	S.T.	8.91	R.L.	6.66	B.R.	9.10
7.	R.A.	7.46	J.L.	7.07	C.L.	8.64
8.	B.A.	9.10	M.C.	8.43	L.A.	8.43
9.	R.M.	8.64	M.G.	8.69	T.C.	8.23
10.	A.P.	9.15	L.J.	7.65	J.L.	7.69
11.	M.R.	8.00	B.T.	8.48	B.D.	7.65
12.	M.W.	7.87	A.R.	8.19	L.R.	7.37
13.	B.Z.	8.86	J.R.	8.80	H.C.	7.49
14.	S.B.	8.14	T.R.	8.43	G.N.	7.56
15.	H.S.	8.14	B.J.	8.69	R.M.	7.73
16.	D.J.	8.23	D.M.	8.48	F.D.	7.73
17.	B.T.	8.14	M.J.	7.65	B.N.	7.96
18.	B.N.	6.33	B.J.	8.48	R.S.	8.64
19.	T.M.	7.44	A.J.	8.29	C.M.	8.28
20.	L.C.	7.68	B.T.	8.23	D.S.	6.90
21.	R.D.	8.53	L.R.	7.60	J.B.	7.77
22.	P.S.	7.60	B.H.	7.69	S.H.	7.60
23.	J.F.	8.75	T.B.	8.14	F.D.	8.80
24.	T.O.	6.97	C.S.	7.77	S.S.	8.53
25.	J.B.	8.29	W.B.	8.23	R.W.	8.43
	$\overline{M}$ = 8.31		$\overline{M}$ = 8.14		$\overline{M}$ = 7.91	

variance to determine which group was the fastest is presented in Table 4.

Table 4

Analysis of Variance of Velocity in Feet Per Second for the First Fourteen Feet of a Race as Executed by Seventy-five Swimmers Performing the Grab, Arms Back, and Circular Arm Swing Starts

SOV	SS	df	M^2	F	P
Among	1.66	2	.83	2.24	N.S.
	26.39	72	.37		
	28.05	74			

[a]An F of 3.13 at the .05 level or 4.92 at the .01 level would have been needed to be significant.

The results of the analysis of variance indicated that there were no significant differences in speed among the grab, arms back, and circular arm swing racing starts.

DESCRIPTIVE AND COMPARATIVE ANALYSIS

Progressive sequence descriptions of the grab, arms back, and circular arm swing starts were presented every tenth of a second throughout the start and dive.

Gross body movements depicted by the head, upper arm, forearm, trunk, thigh, lower leg, and foot were abstracted. A progressive link sequence description of the three starts was also furnished to facilitate a more accurate understanding of the mechanics employed by the swimmers as they executed their starts.

Initial Starting Position

Refer to Figures 6-8 on pages 72-74 for the initial starting position exhibited by each of the three subjects as depicted by stick figures and Figure 9 on page 75 for the sequence photo start.

The grab start subject assumed the ready position by approaching the leading edge of the starting platform. He placed his feet, with toes curled over the edge, about six inches apart. By dorsiflexing at the ankle joints and flexing at the knees, hips, and trunk the swimmer was able to reach down and grab the leading edge of the starting block just to the lateral sides of his feet. It appeared that the subject's forearms were slightly flexed at the elbows. The head was tilted back through cervical hyperextension. In the mentioned ready state it seemed that the subject rocked forward as far as possible in

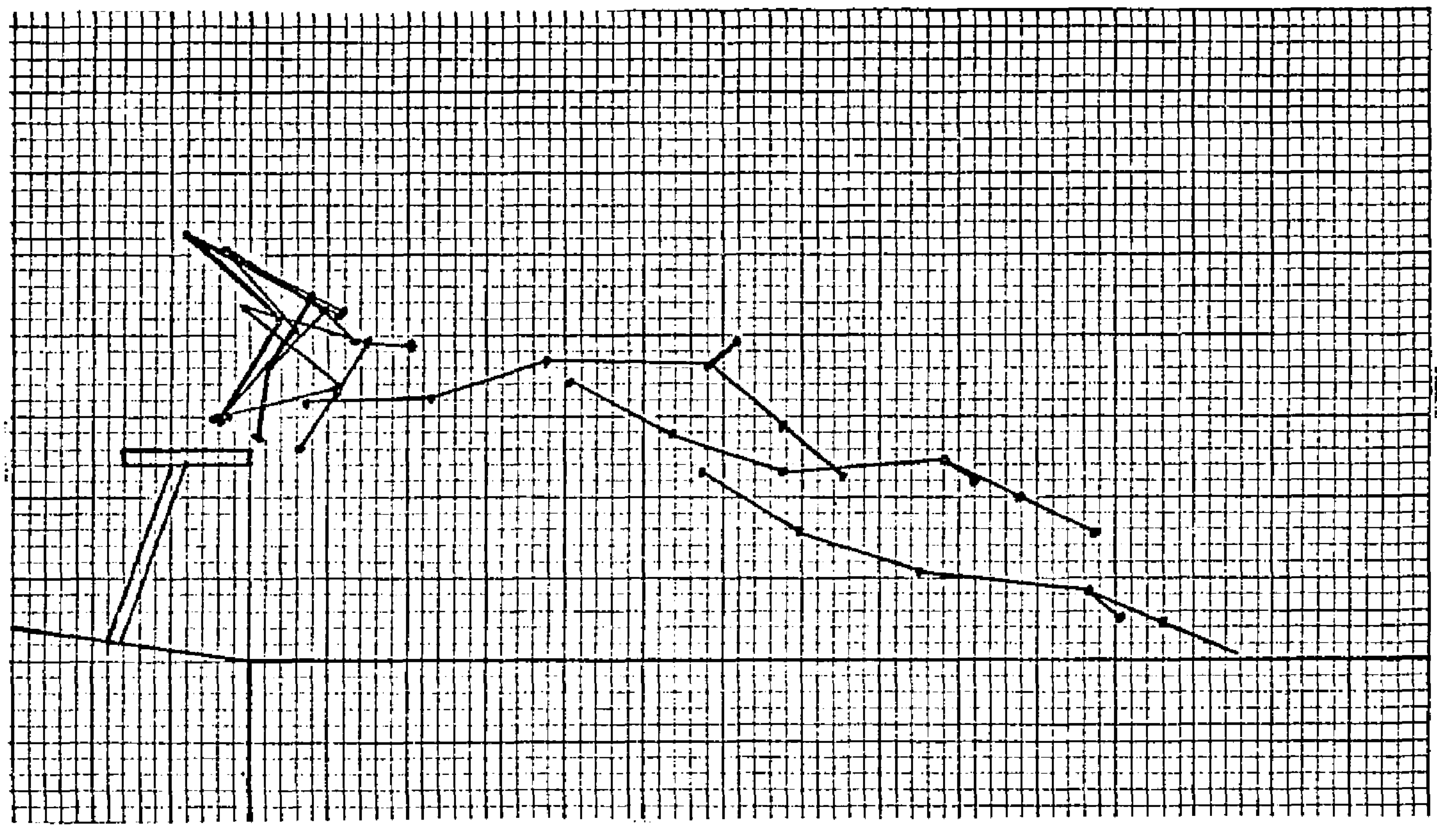


Figure 6. Stick Figure Representation of the Gross Body Movements Depicted by the Grab Start Swimmer Every Twentieth of a Second.

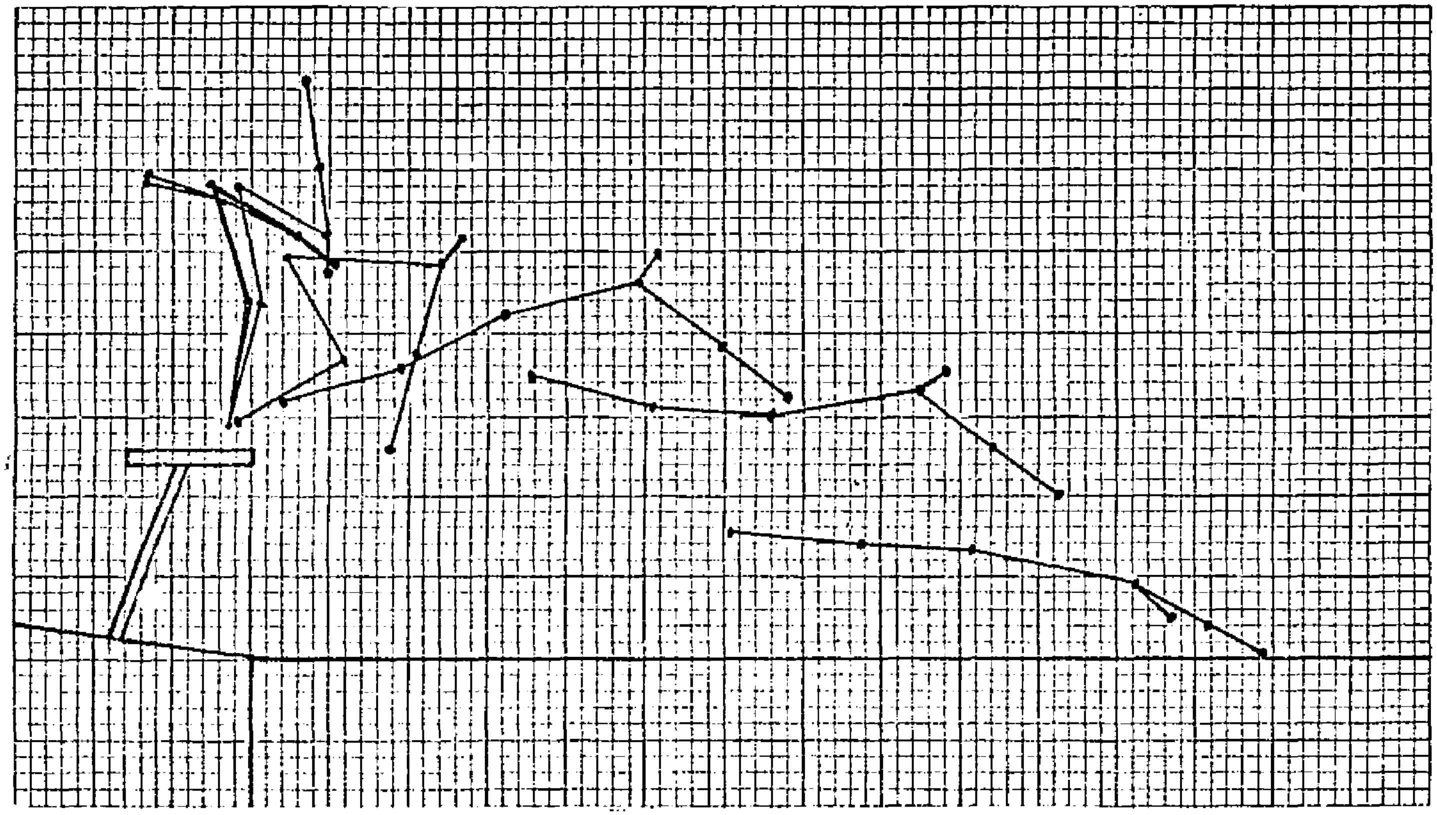


Figure 7. Stick Figure Representation of the Gross Body Movements Depicted by the Arms Back Swimmer Every Twentieth of a Second.

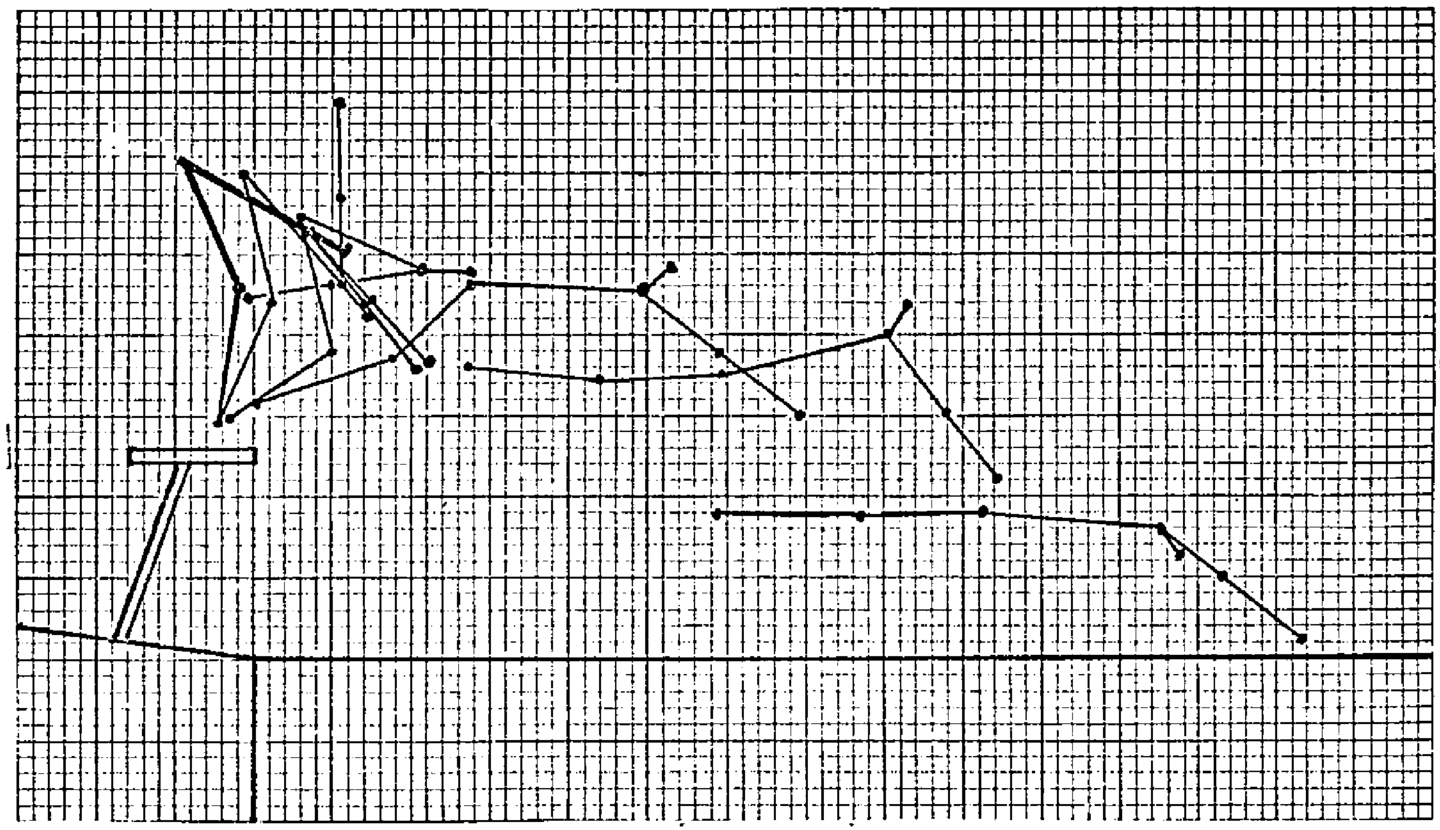
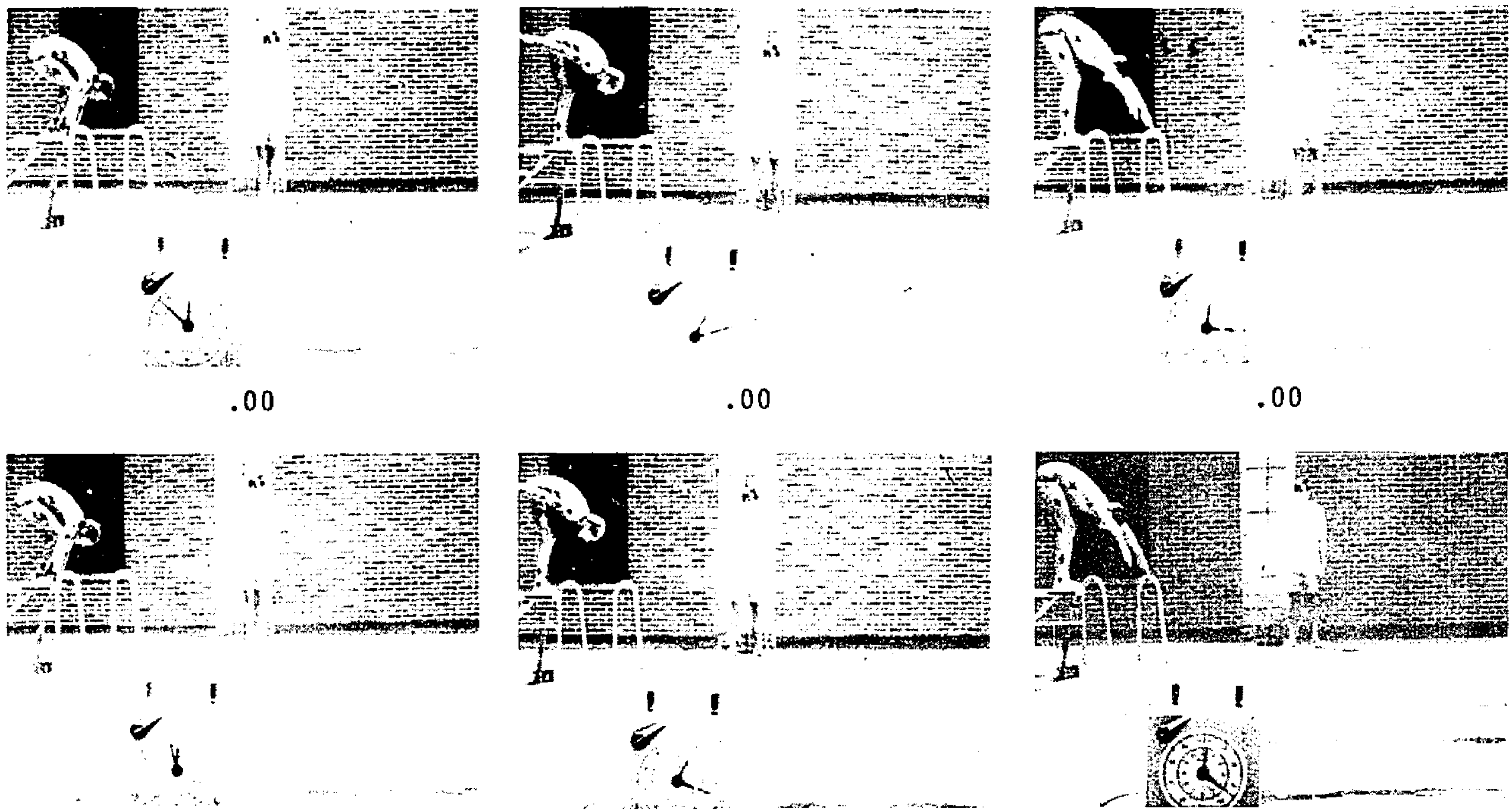


Figure 8. Stick Figure Representation of the Gross Body Movements Depicted by the Circular Arm Swing Swimmer Every Twentieth of a Second.



.00	.00	.00
.10	.10	.10
Grab Start	Arms Back Start	Circular Arm Swing Start

Figure 9. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Starts Every .00 and .10 Seconds After the Starting Command.

anticipation of the starting command. Film analysis further revealed that the center of gravity was slightly in front of the leading edge of the starting block.

The arms back subject assumed the ready position for the start by approaching the leading edge of the starting platform and placing his feet shoulder's width apart. By bending forward at the waist the swimmer inclined his upper torso toward the water to about a forty degree angle. His extended arms were positioned along the sides of the trunk and pointing in a backward direction. Slight cervical hyperextension was noted. In addition, a small amount of flexion was observed in the knees. Film analysis revealed that the subject's center of gravity was located slightly behind the leading edge of the starting block and higher above it than the grab start subject.

The circular arm swing subject assumed the ready position for the start by approaching the leading edge of the starting platform and placing his feet about six inches apart. He bent forward at the waist and assumed a pose in much the same manner as the arms back subject. However, the circular arm swing subject extended his arms to an overhead position and pointing toward the water at about a forty-five degree angle.

.10 Second

Refer to Figure 9 on page 75 for the gross body movements exhibited by the three subjects one-tenth of a second after the starting command.

Film observation revealed that none of the three subjects had had time to react to the starting command. Therefore, no movement transpired during the first tenth of a second.

.20 Second

Refer to Figures 6-8 on pages 72-74 for the stick figures and Figure 10 on page 78 for the gross body movements exhibited by the three subjects two-tenths of a second after the starting command.

The grab start subject, two-tenths of a second after the gunshot, still had not reacted to the starting command.

The arms back subject reacted to the starting command in approximately nineteen hundredths of a second. The initial gross movements noted were slight flexion at the waist and clockwise rotation of the arms.

The circular arm swing subject reacted to the starting command in approximately eighteen hundredths of a second. The initial gross body movements noted were slight flexion at the knees and counterclockwise rotation of the arms.

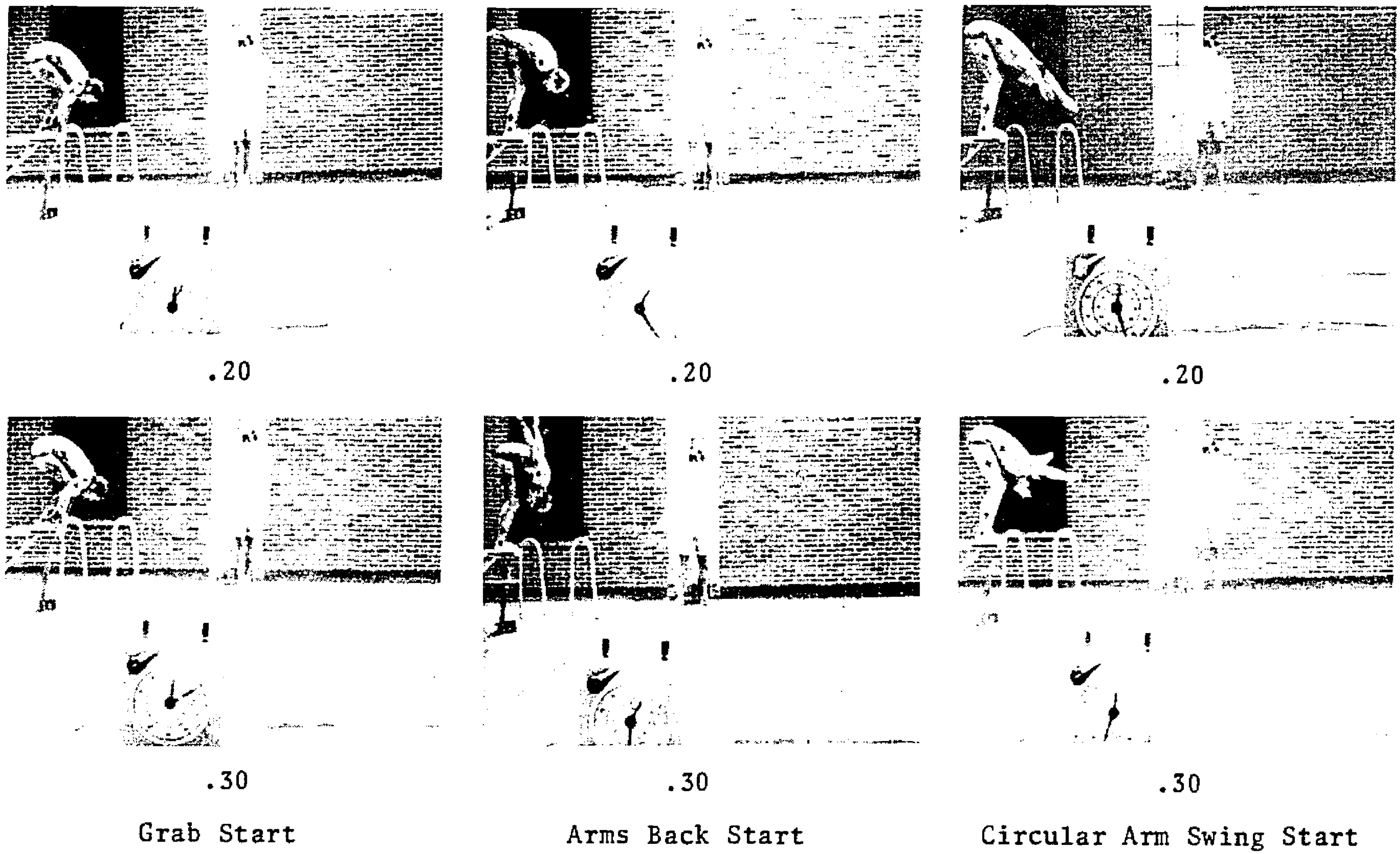


Figure 10. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Starts Every .20 and .30 Seconds After the Starting Command.

.30 Second

Refer to Figure 10 on page 78 for the gross body movements exhibited by the three subjects three-tenths of a second after the starting command.

The grab start subject reacted to the starting command in approximately twenty-one hundredths of a second. The initial gross body movements were flexion at the knees and elbows. The resultant actions drew the swimmer into a tighter crouch and precipitated his fall toward the water.

The arms back subject continued flexing in the lumbar and cervical spines and rotating the extended arms in a clockwise direction. The resultant actions brought the swimmer's head in close proximity to his knees and left his arms in a vertical position. The center of gravity appeared to move outward as well as downward.

The circular arm swing subject sustained flexion at the knees, lumbar spine, and rotation of the extended arms in a counterclockwise direction. The action of the arms helped to lower the upper torso down against the thighs. The center of gravity appeared to move outward as well as downward.

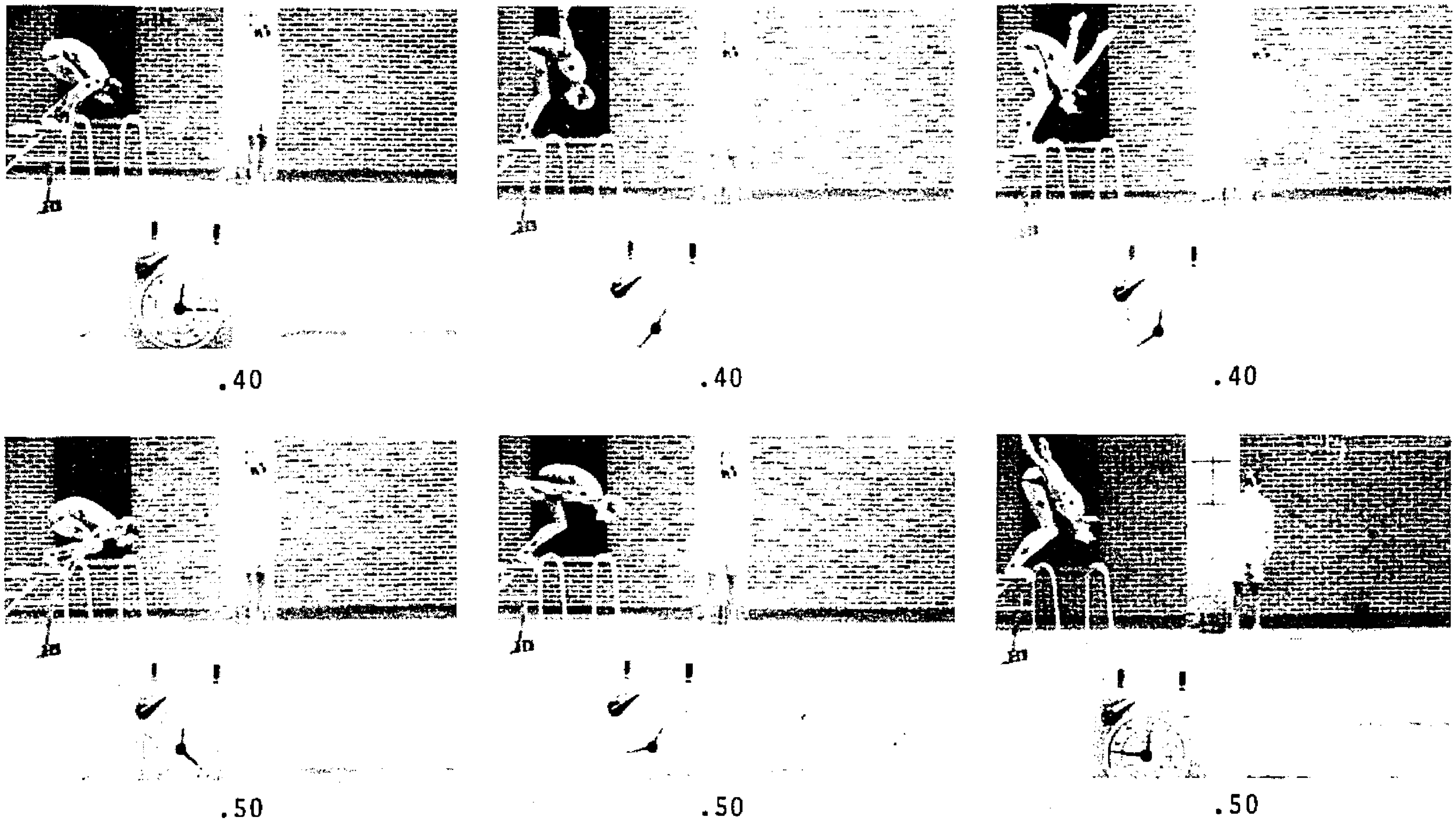
.40 Second

Refer to Figures 6-8 on pages 72-74 for the stick figures and Figure 11 on page 81 for the gross body movements exhibited by the three subjects four-tenths of a second after the starting command.

The grab start subject maintained flexion at elbows which drew the body into a tighter crouch primarily through knee and ankle flexion. It appeared that the body was propelled more downward than outward.

The arms back subject's center of gravity remained relatively high on the starting block. As he kept up his forward roll the swimmer began extending his trunk through lumbar extension. At the same time, however, the subject continued flexing at the knees and ankles. Throughout the interim the arms ceased clockwise rotation and started moving in a counter-clockwise direction. The body moved primarily in an outward direction.

The circular arm swing subject continued rotating his arms in a counterclockwise direction. This action kept the trunk close to the subject's thighs. At the same time knee and ankle flexion caused the body to move outward as well as down.



Grab Start | Arms Back Start | Circular Arm Swing Start

Figure 11. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Starts Every .40 and .50 Seconds After the Starting Command.

.50 Second

Refer to Figure 11 on page 81 for the gross body movements exhibited by the three subjects five-tenths of a second after the starting command.

The grab start subject had drawn himself into a maximum crouch by pulling down on the starting platform. Continued flexion was noted in the knees and ankles which caused the heels to lift off the starting platform. His trajectory continued more downward than outward.

The arms back subject upheld an outward trajectory. His ankles continued to dorsiflex causing the heels to lift off the starting block. Furthermore, the knees continued flexing. As the swimmer rolled forward his trunk lifted through lumbar extension. In addition, the arms continued to rotate in a counterclockwise direction.

The circular arm swing subject appeared to make the same basic movements as those of the arms back subject, only more slowly. As the swimmer rolled forward the ankles and knees continued flexing. In addition, the arms were rotating in a counterclockwise direction. Also, the body trajectory was more outward than down.

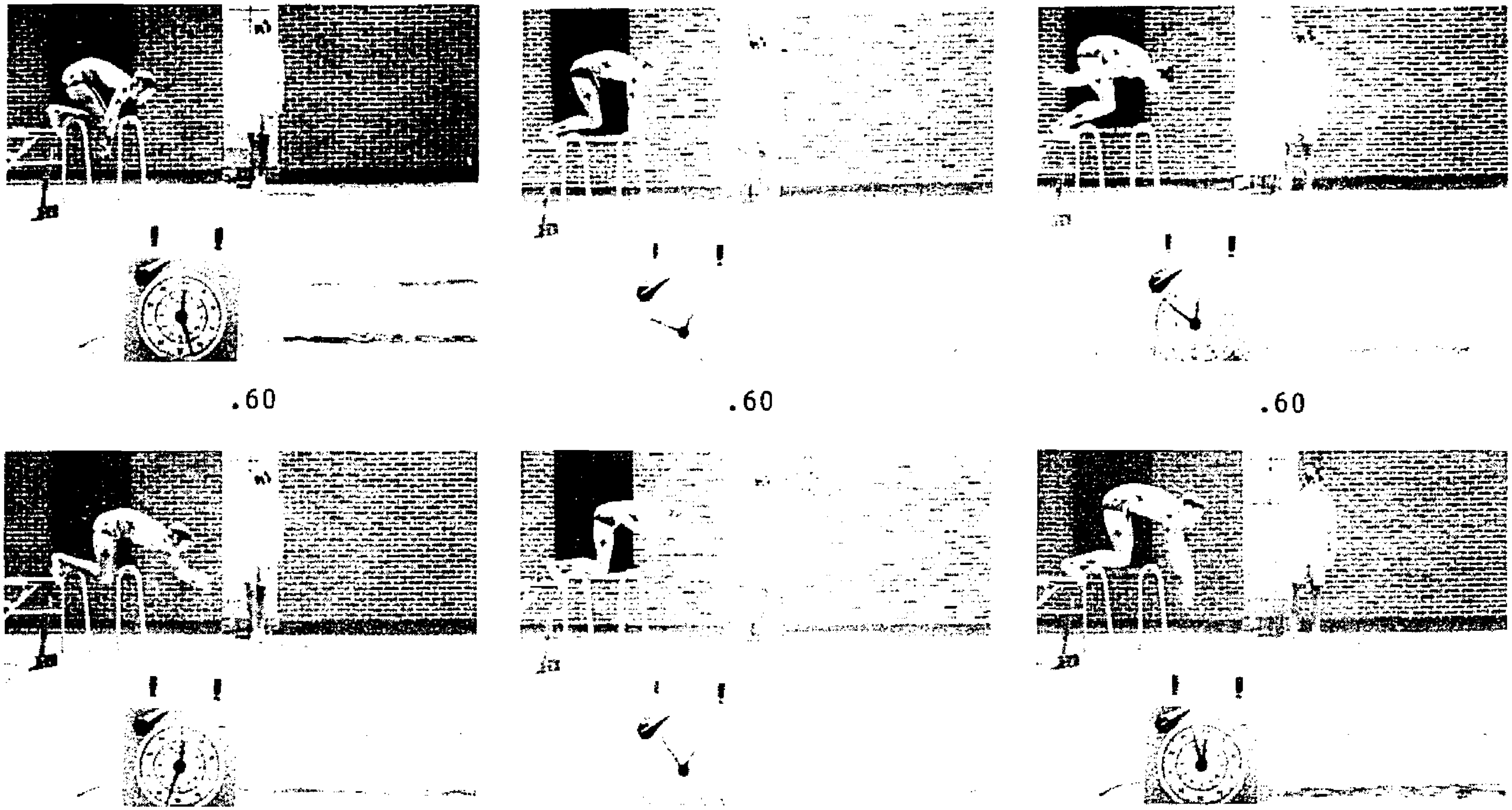
.60 Second

Refer to Figures 6-8 on pages 72-74 for the stick figures and Figure 12 on page 84 for the gross body movements exhibited by the three subjects six-tenths of a second after the starting command.

The grab start subject released his hold on the leading edge of the starting block and began extending himself through ankle, knee and lumbar extension. He also began rotating his arms in a counterclockwise direction. It was at this point that the subject's body trajectory began leveling off.

The arms back subject maintained lumbar extension which kept the upper torso and center of gravity relatively high on the starting block. At the same time, however, the ankles and knees sustained flexion while the arms upheld counterclockwise rotation. Thus, as the body accelerated toward the water it was in an outward and downward direction.

The circular arm swing subject maintained the same movement patterns as those developed by the arms back swimmer but on a delayed basis. The swimmer prolonged ankle and knee flexion, slight lumbar extension, and counterclockwise arm rotation. Thus,



.60 .60 .60

.70 .70 .70

Grab Start | Arms Back Start | Circular Arm Swing Start

Figure 12. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Starts Every .60 and .70 Seconds After the Starting Command.

the body was projected equally outward as well as downward. In addition, the heels began lifting off the starting block.

.70 Second

Refer to Figure 12 on page 84 for the gross body movements exhibited by the three subjects seven-tenths of a second after the starting command.

The grab start subject slowed his pronounced downward trajectory and began moving in a more noticeable horizontal direction. He gained body velocity through ankle, knee, and hip extension. Counter-clockwise arm rotation was also maintained.

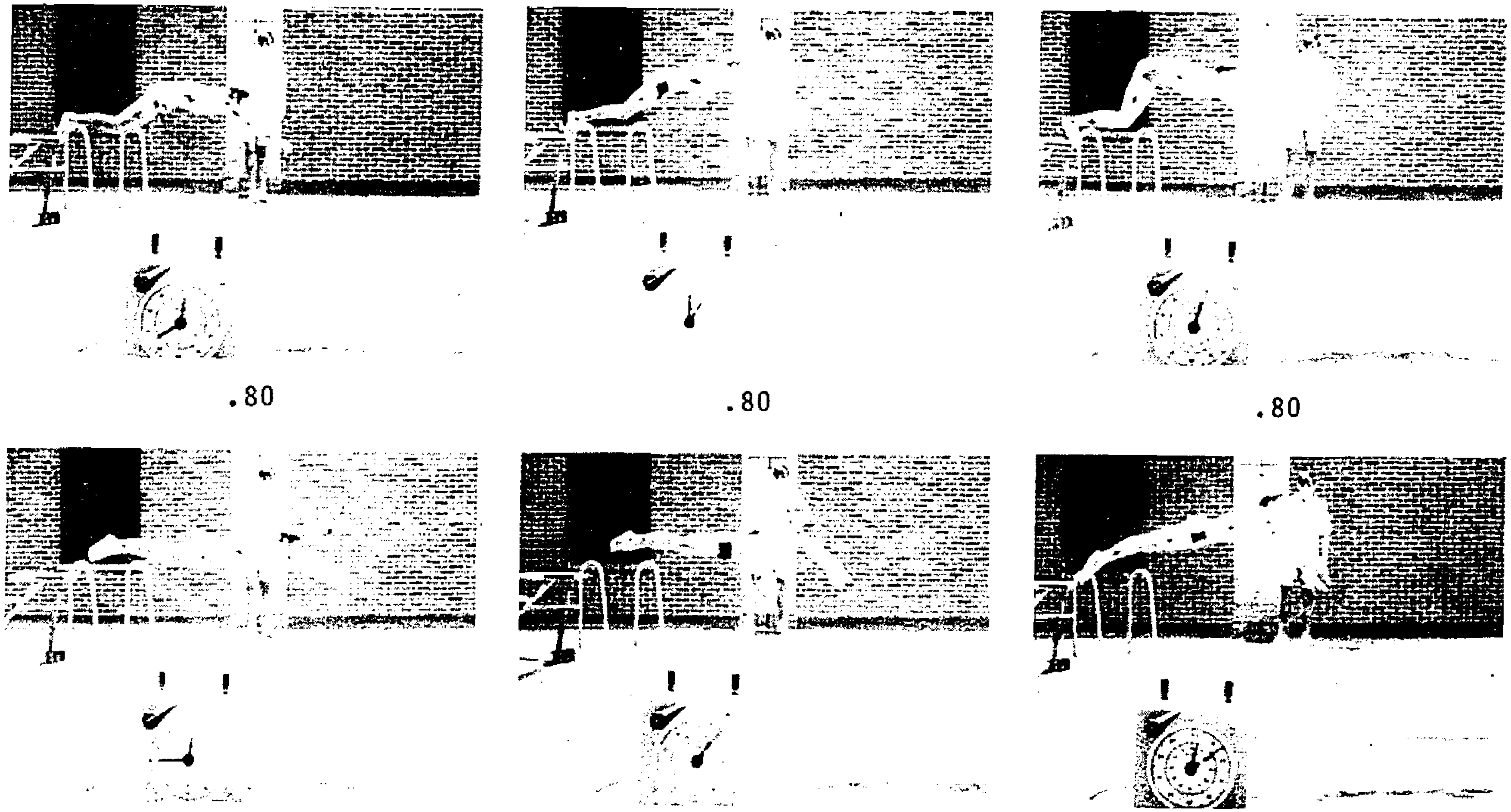
The arms back subject maintained his diagonal trajectory off the starting block. The greatest amount of body movement was ascertained at the knees and in particular the arms. Since the last movement description, the knees further extended driving the body horizontally. The arms rotated from a downward vertical position to one in which they were extended in front of the body. The trunk sustained a horizontal position as the body continued its roll off the starting block.

The circular arm swing subject maintained his belated congruent movements in relation to the arms back subject. His arms rotated from a back horizontal position to one in which they pointed almost vertically downward. Extension of the knees resulted in a sustained diagonal trajectory as the body fell toward the water. During this phase the lower legs were horizontal, the thighs vertical, and the trunk horizontal to the water.

.80 Second

Refer to Figures 6-8 on pages 72-74 for the stick figures and Figure 13 on page 87 for the gross body movements exhibited by the three subjects eight-tenths of a second after the starting command.

The grab start subject had by eight-tenths of a second almost extended himself on the starting block. The trunk was completely extended while some flexion was still noted at the hip, knee, and ankle joints. Also, the head remained cervically hyperextended. It appeared that horizontal body momentum was developed successively through the trunk, hip, knee, and ankle extension. Arm rotation was by this time almost completed. As the swimmer prepared to leave the starting block his body was almost horizontal to the top of it.



.90 .90 .90

Grab Start Arms Back Start Circular Arm Swing Start

Figure 13. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Starts Every .80 and .90 Seconds After the Starting Command.

The arms back subject had by eight-tenths of a second almost extended himself on the starting block. The trunk was completely extended while some flexion remained in the hips, knees, and ankles. Also, the head was tilted back through cervical hyperextension. As noted in the previous subject, the arms back subject appeared to have gained horizontal body momentum through successive extension of the trunk, hips, knees, and ankles. Arm rotation was by this time almost completed. As the swimmer prepared to leave the starting blocks, his body was inclined upward more than the grab start subject.

The circular arm swing subject was by eight-tenths of a second still extending himself on the starting block. Unlike the other two subjects, he was decidedly flexed at the trunk, hip, knee, and ankle joints and hyperextended in the cervical spine. However, the arm rotation had ceased.

.90 Second

Refer to Figure 13 on page 87 for the gross body movements exhibited by the three subjects nine-tenths of a second after the starting command.

The grab start swimmer left the starting block .83 of a second after the starting command. While in the air the swimmer was completely extended and in a horizontal position. The head was hyperextended and the arms extended overhead. Film observations revealed thatthe body as a whole was rotating clockwise.

The arms back subject left the starting block .83 of a second after the starting command. While in the air the swimmer was completely extended except for pronounced hyperextension in the lumbar spine. As a result, the legs were parallel to the top of the starting platform with the upper torso inclined upward. The arms were extended and pointing toward the water at about forty-five degrees. Film observation revealed that the body as a whole was rotating clockwise.

The circular arm swing subject left the starting block .89 of a second after the starting command. As he left the starting block the swimmer was completely extended. The head was tilted back through cervical hyperextension. The arms had terminated their counter-clockwise rotation and were pointing toward the water at about a forty-five degree angle. The subject was inclined upward about twenty degrees as he left the starting block.

<u>1.00 Second</u>

Refer to Figures 6-8 on pages 72-74 for the stick figures and Figure 14 on page 91 for the gross body movements exhibited by the three subjects one second after the starting command.

The grab start subject continued clockwise body rotation as he fell toward the water. During the interim the swimmer arched his back and lowered his head between outstretched arms.

The arms back subject continued clockwise body rotation as he fell toward the water. During the interim the head began returning to an extended position from one of maximum hyperextensions.

The circular arm swing subject arched his back and rotated clockwise as he fell toward the water. Once again, his body movements were reminiscent of those of the arms back subject.

<u>1.10 Seconds</u>

Refer to Figure 14 on page 91 for the gross body movements exhibited by the three subjects one and one-tenth seconds after the starting command.

The grab start subject continued in the trajectory of a freely falling object. The same relative body position was maintained since the last frame except for clockwise body rotation and lowered head.

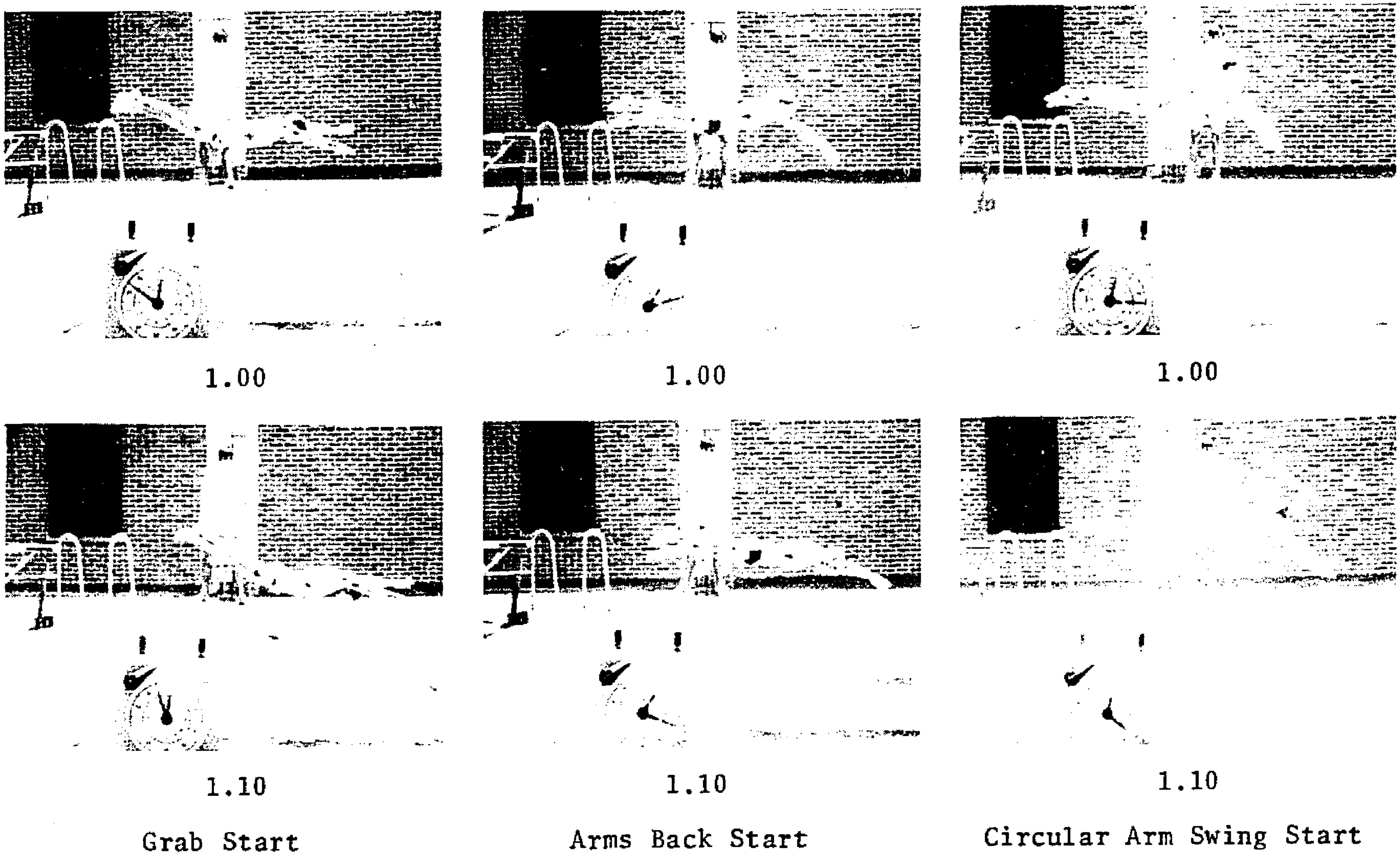


Figure 14. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Starts Every 1.00 and 1.10 Seconds After the Starting Command.

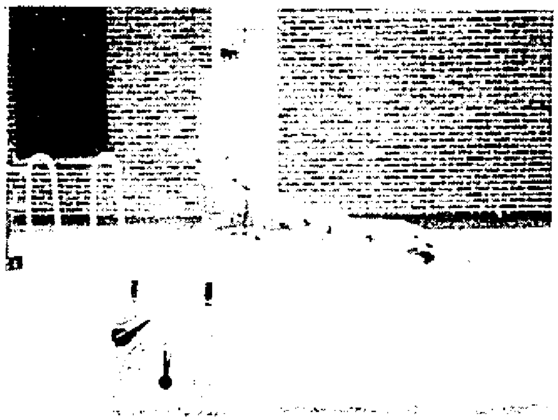
The arms back subject continued his trajectory through the air. As he neared the water he completely extended his body with the arms extended overhead. Slight clockwise body rotation was also noted since the last frame.

The circular arm swing subject maintained the trajectory of a freely falling object after having left the starting block. As his body rotated clockwise, film analysis revealed that the swimmer's lumbar and cervical spines began returning to an extended position after having reached maximum hyperextension.

1.20 Seconds

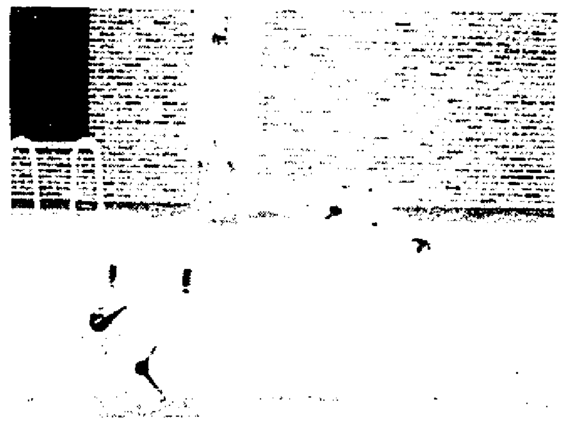
Refer to Figures 6-8 on pages 72-74 for the stick figures and Figure 15 on page 93 for the gross body movements exhibited by the grab start subject 1.14 seconds, the arms back subject 1.18 seconds, and the circular arm swing subject one and two-tenths seconds after the starting command.

The grab start subject's hands entered the water 1.14 seconds after the starting command. The swimmer entered the water in an extended position with the arms outstretched and overhead. Further film observations revealed that the subject's back was slightly arched. His angle of entry appeared to be more obtuse than that of the other two subjects.



1.14

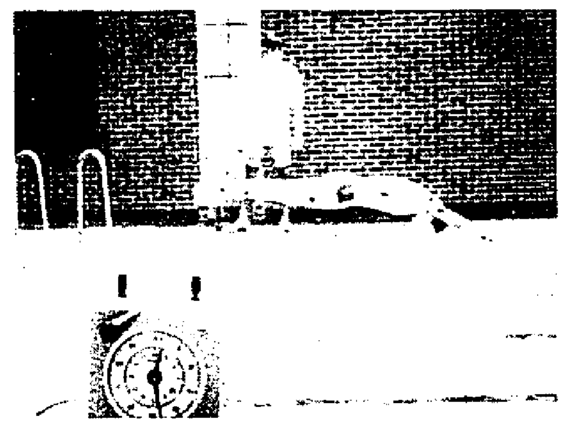
Grab Start



1.18

Arms Back Start

1.20



1.22

Circular Arm Swing Start

Figure 15. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Swimmers As The Hands Entered the Water.

The arms back subject's hands entered the water 1.18 seconds after the starting command. The swimmer entered the water in a piked position with the arms extended overhead and the head slightly flexed. He entered the water in a more acute angle than the grab start subject.

The circular arm swing subject approached water entry in an extended position with the arms outstretched andpointing down the trajectory path. The head was also slightly flexed as the body continued clockwise rotation.

1.30 Seconds

Refer to Figure 15 on page 93 for the gross body movements of the circular arm swing subject 1.22 seconds after the starting command.

The circular arm swing subject entered the water 1.22 seconds after the starting command. His body was completely extended except for the outstretched arms and lowered head. He entered the water in an almost flat angle.

CINEMATOGRAPHIC ANALYSIS OF ANGLE OF TAKE-OFF, TAKE-OFF VELOCITY, AND RANGE

Three of the sub-purposes of this study were to determine each subject's: (1) angle of take-off;

(2) take-off velocity; and (3) horizontal distance that the center of gravity traversed during airborne flight. Refer to Figure 16 on page 96 for the sequence photo and Composite Graph 1 on page 97 for the computed centers of gravity.

Angle of Take-off of Center of Gravity

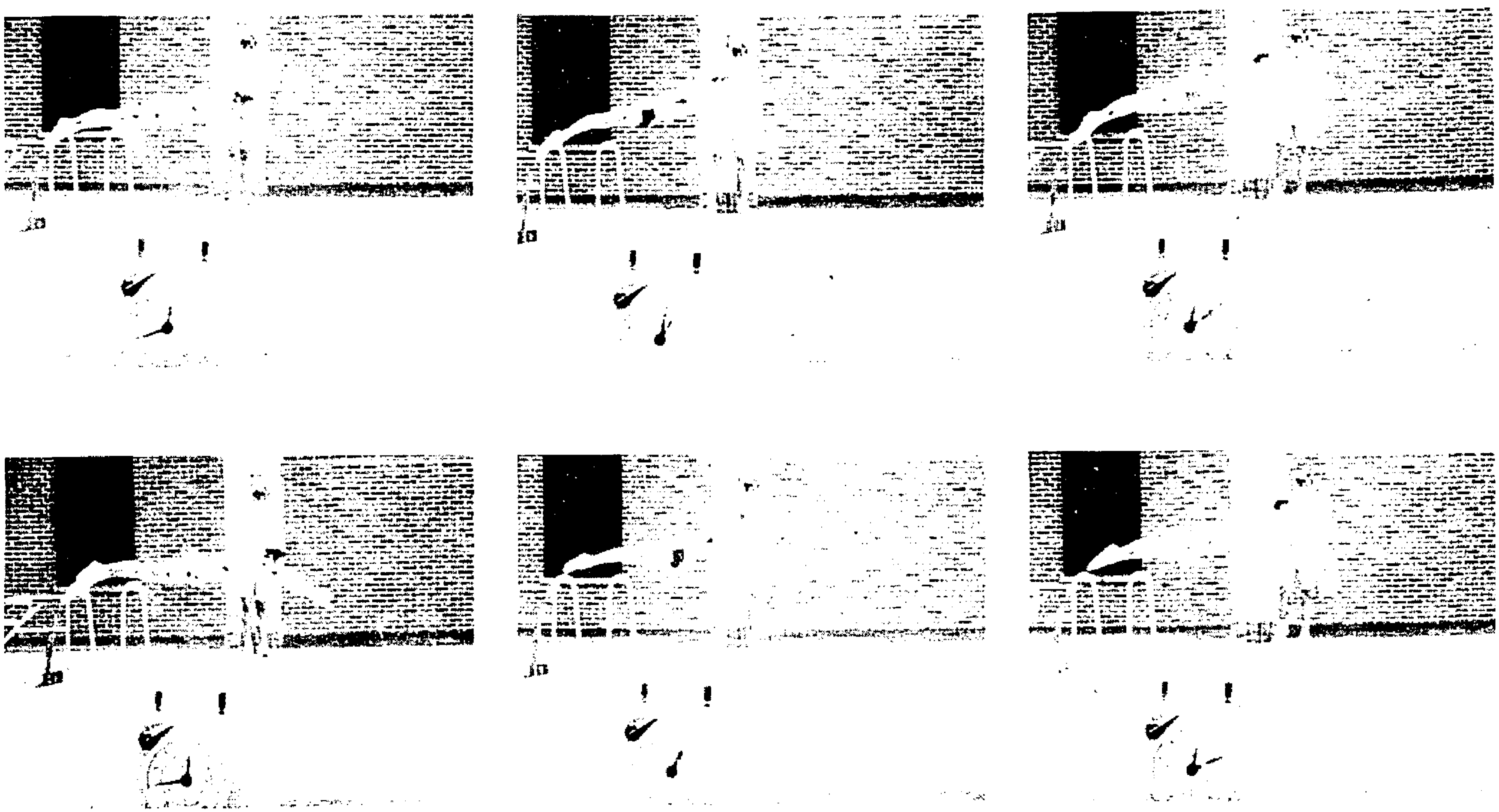
The take-off angle of each subject's center of gravity was determined by locating the center of gravity as the swimmer left the starting block and two film frames later. The grab start subject left the starting block in a downward trajectory of fifteen degrees; the arms back subject, minus eleven degrees; and the circular arm swing subject, minus ten degrees.

Take-off Velocity

The take-off velocity of each subject was determined by utilizing the following formula: $V = \frac{D}{t}$.

The grab start subject left the starting block with a velocity of 14.2 feet/second. During the interim between the two film frames shown in Figure 16 on page 96 and Composite Graph 1 on page 97, he moved 5.8 inches in .034 of a second.

The arms back subject left the starting block with a velocity of 14.8 feet/second. During the

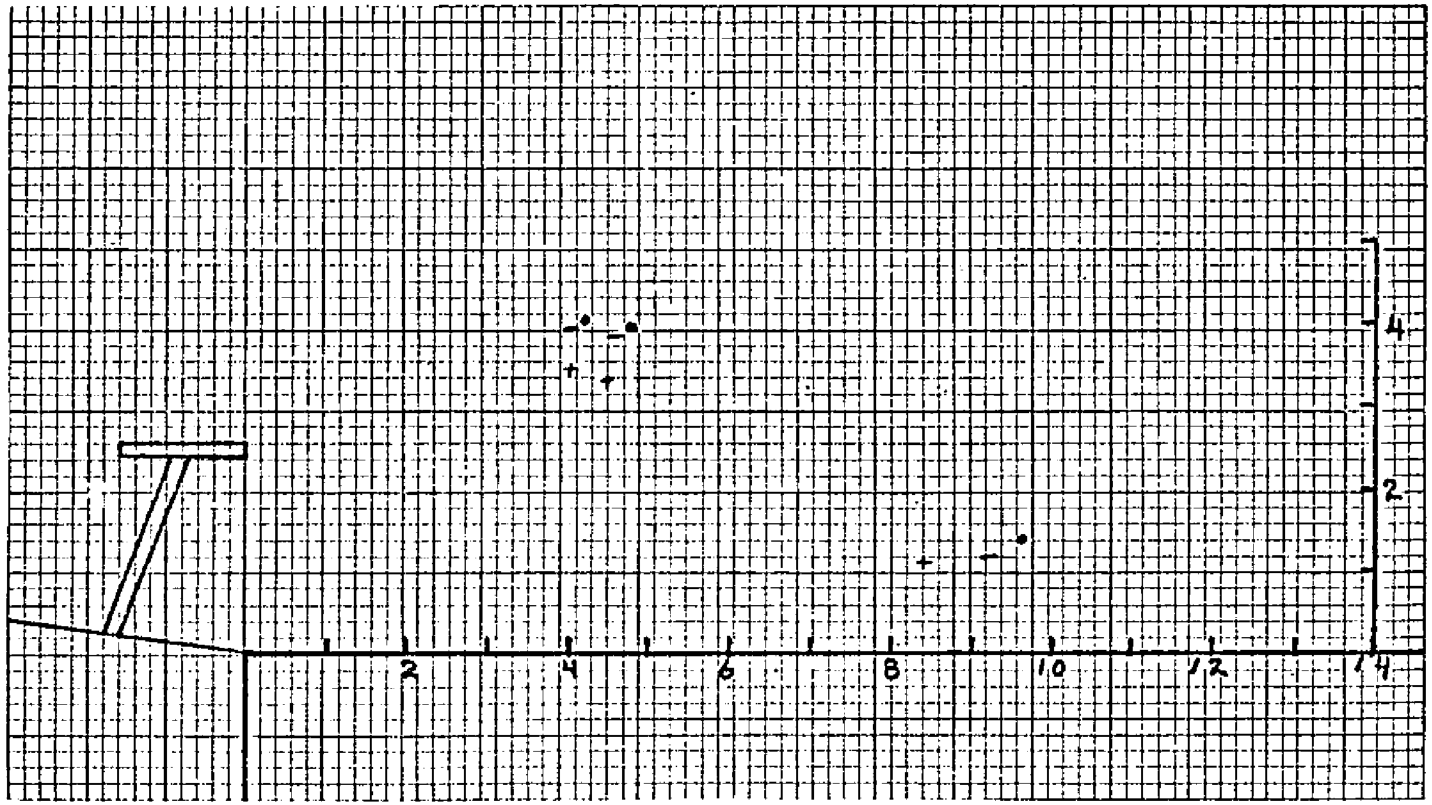


Grab Start Arms Back Start Circular Arm Swing Start

Figure 16. Sequence Photos Revealing the Grab, Arms Back, and Circular Arm Swing Subjects as They Leave the Starting Block and Two Film Frames Later.

Composite Graph 1

Center of Gravity of Three Swimmers as They Leave the Starting Block, Two Film Frames Later, and as the Hands Enter the Water



Grab Start Subject (+++)
Arms Back Subject (----)
Circular Arms Swing Subject (...)

interim between the two film frames shown in Figure 16 and Composite Graph 1, he moved 6 inches in .034 of a second.

The circular arm swing subject left the starting block with a velocity of 15.4 feet/second. During the interim between the two film frames shown in Figure 16 and Composite Graph 1, he moved 6.3 inches in .034 of a second.

Range

The horizontal distance that each subject's center of gravity traversed while airborne was determined from film analysis. The grab start subject's center of gravity moved 4.33 feet; the arms back subject's, 5.08 feet; and the circular arm swing subject's, 5.25 feet.

COMPUTATIONAL VALIDATION

Three sub-purposes of this study were to determine each subject's: (1) angle of take-off; (2) take-off velocity; and (3) horizontal distance that the center of gravity traversed during airborne flight. In order to validate the computed values they were inserted into the two following formulae.

If the results obtained from the formulae corresponded to the scaled values taken from the film analysis, they were considered valid. The two formulae were:

1. $R = V_o \cos \theta \, t$

   Where R = Range of center of gravity during airborne flight.

   V_o = take-off velocity of center of gravity.

   θ = angle of take-off of center of gravity.

   t = time of center of gravity during airborne flight.

   a. The grab start subject's scaled Range was 4.33 feet. Refer to Composite Graph 1 on page 97 for the scaled value.

      The grab start subject's computed Range was:

      R = 14.2 feet/second x .97 x .31 second
      R = 4.27 feet

   b. The arms back subject's scaled Range was 5.08 feet. Refer to Composite Graph 1 on page 97 for scaled value.

      The arms back subject's computed Range was:

      R = 14.8 feet/second x .98 x .35 second
      R = 5.08 feet

   c. The circular arm swing subject's scaled Range was 5.25 feet. Refer to Composite Graph 1 on page 97 for scaled value.

      The circular arm swing subject's computed Range was:

      R = 15.4 feet/second x .98 x .33 second
      R = 4.98 feet.

2. $h = 1/2\ gt^2 + V_o \sin \theta\ t$

Where: h = vertical distance center of gravity falls.

g = 32 feet/sec^2 or pull of gravity.

t = time center of gravity falls.

V_o = take-off velocity of center of gravity.

θ = take-off angle of center of gravity.

a. The grab start subject's scaled center of gravity fell 2.42 feet. Refer to Composite Graph 1 on page 97 for scaled value.

The grab start subject's computed fall was:

h = 16 feet/second^2 x (.31 second)^2 + 14.2 feet/second x .26 x .31 second
h = 2.68 feet.

b. The arms back subject's scaled center of gravity fell 2.67 feet. Refer to Composite Graph 1 on page 97 for scaled value.

The arms back subject's computed fall was:

h = 16 feet/second^2 x (.35 second)^2 + 15.4 feet/second x .19 x .35 second
h = 2.94 feet

c. The circular arm swing subject's scaled center of gravity fell 2.50 feet. Refer to Composite Graph 1 on page 97 for scaled value.

The circular arm swing subject's computed fall was:

$$h = 16 \text{ feet/second}^2 \times (.33 \text{ second})^2 + 15.4 \text{ feet/second} \times .17 \times .33 \text{ second}$$
$$h = 2.61 \text{ feet}$$

Refer to Table 5 on page 102 for the mechanical qualities indicative of the three starts.

COMPARATIVE TRAJECTORY ANALYSIS

Although no significant differences of speed existed among the three groups of swimmers some dissimilarities in the mechanical actions of the three selected subjects were noted. The most readily evident differences lay in the actions of the arms and the centers of gravity.

Wrist Trajectory

As shown in Composite Graph 2 on page 104 the wrist trajectories, which revealed the actions of the arms, of the three subjects were compared. Observation of the three trajectories revealed that they were not congruent. A greater amount of discrepancy existed among them than the other body parts. Of course, this was due to the nature of each start. The reason they were considered separate starts was attributed to the pre-set positioning of the arms.

Table 5

Mechanical Qualities Indicative of the Grab, Arms Back and Circular Arms Swing Starts

Mechanical Description	Mechanical Quality: Grab Start	Arms Back Start	Circular Arms Start
1. Initial reaction time to starting command	.21 seconds	.19 seconds	.18 seconds
2. Time of movement on block	.83 seconds	.83 seconds	.89 seconds
3. Time of airborne flight of center of gravity	.31 seconds	.35 seconds	.33 seconds
4. Total elapsed time for dive	1.14 seconds	1.18 seconds	1.22 seconds
5. Take-off angle of center of gravity	-15 degrees	-11 degrees	-10 degrees
6. Take-off velocity of center of gravity	14.3 feet/second	14.8 feet/second	15.4 feet/second
7. Scaled horizontal range center of gravity traversed during airborne flight	4.33 feet	5.08 feet	5.25 feet

Table 5 (continued)

Mechanical Description	Grab Start	Mechanical Quality Arms Back Start	Circular Arms Start
8. Computed horizontal range center of gravity traversed during airborne flight	4.27 feet	5.08 feet	4.98 feet
9. Scaled vertical distance center of gravity fell during airborne flight	2.42 feet	2.67 feet	2.50 feet
10. Computed vertical distance center of gravity fell during airborne flight	2.68 feet	2.94 feet	2.61 feet
11. Horizontal distance hands entered the water	12.00 feet	12.60 feet	13.00 feet

Composite Graph 2

Wrist Trajectories of the Grab, Arms Back, and Circular Arm Swing Swimmers Every .10 of a Second

Grab Start Subject (+++)
Arms Back Subject (----)
Circular Arms Swing Subject (···)

The grab start subject's wrist trajectory began close to the leading edge of the starting platform. As the subject began his dive he pulled himself toward the water. During this transaction his wrists remained in approximately the same position. After the subject had drawn himself into a tight crouch he began extending himself on the starting block. It was at the beginning of body extension that the subject released the starting block. Since the arms were behind the extending swimmer the first movement of the wrists was a counterclockwise rotation. The arms and wrists were subsequently rotated under and in front of the subject as he extended himself on the starting block. Upon leaving the starting block the subject's wrists followed a convex parabolic trajectory toward the water.

The arms back subject's wrist trajectory began on the horizontal as he placed his extended arms behind him. Initial body movement revealed that the wrists moved in a clockwise direction to an almost vertical overhead position. As the swimmer began extending himself on the starting block his arms began rotating from their hyperextended position in a counterclockwise direction. Throughout the dive the arms remained extended. Upon leaving the starting block the wrist moved in a convex parabolic trajectory toward the water.

The circular arm swing subject's wrist trajectory began slightly above and in front of the leading edge of the starting block. Photographs of the circular arm swing subject revealed that the initial wrist movement was counterclockwise. Throughout the momentum producing phase of the start the wrist continued in a vigorous counterclockwise direction. As the subject left the starting block the wrist moved in a convex parabolic trajectory toward the water.

In summary of the three wrist trajectories, it was noted that during the last half of the start or roughly from the time that the hands passed the leading edge of the starting block, the trajectories were congruent in nature. Thus, it would seem that the effect of the arm patterns upon the overall effectiveness of the dives had to occur during the initial stages of the start.

Center of Gravity Trajectory

As shown in Composite Graph 3 on page 107 the centers of gravity trajectories of the three subjects were shown. The center of gravity, more than any other reference point, revealed the cumulative effect of various actions upon the total body trajectory.

Composite Graph 3

Body Center of Gravity Trajectories of the Grab, Arms Back, and Circular Swing Swimmers Every .10 of a Second

Grab Start Swimmer (+++)
Arms Back Swimmer (----)
Circular Arms Swing Swimmer (•••)

At the onset of the skill the grab start subject's center of gravity was located approximately twenty-one vertical inches above the leading edge of the starting block and slightly in front of it. Thus, it appeared that the subject's center of gravity was outside the base of support. The initial movement of the center of gravity was in a downward and outward trajectory of about forty-five degrees. The relatively initial obtuse body trajectory was attributed to the downward pull of the arms upon the starting block. As the subject released his hold on the starting block and began extending himself his center of gravity trajectory became more acute. Also, the body acceleration was the greatest during the extending period. The body momentum appeared to be developed successively through trunk, hip, knee, and ankle extension. Upon leaving the starting block the subject's center of gravity trajectory had almost leveled off. As the swimmer fell toward the water his center of gravity followed the convex parabolic trajectory of a freely falling object.

The arms back subject's center of gravity at the onset of the skill was located approximately twenty-eight inches above the leading edge of the starting block and slightly behind it. As the swimmer commenced initial body movement the center of gravity began a more pronounced outward than downward trajectory of about thirty degrees. Throughout the interim on the starting block the swimmer's trajectory remained relatively unchanged. It was only toward the end of the body extension on the starting block that the trajectory began to level off. The comparatively stable outward fall of the center of gravity while the subject was on the starting block was attributed, in part, to the counterclockwise rotary effect of the arms. As the arms swung underneath the body and upward, their momentum tended to lift the body. Most of the body momentum accrued successively through trunk, hip, knee, and ankle extension. Also, part of the body momentum was attributed to the rotary effect of the arms. As the subject left the starting block his center of gravity traveled the convex parabolic trajectory of a freely falling object.

The center of gravity trajectory exhibited by the circular arm swing subject was basically the same as that of the previous swimmer. At the onset of the skill the center of gravity was located approximately twenty-nine inches above the leading edge of the starting block and slightly behind it. The initial movement of the center of gravity was in an outward and downward direction of about thirty degrees. The relative stableness of the trajectory was due, in part, to the counterclockwise rotation of the arms. Toward the end of the body's extension on the starting block cessation of the upward arm rotation keptthe body relatively high. Most of the body momentum was developed successively through trunk, hip, knee, and ankle extension. A slight amount of body momentum was attributed to the rotary effects of the arms. As the body left the starting blocks the center of gravity followed the trajectory of a freely falling object.

CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

The purpose of this study was two-fold. First, this investigator attempted to determine whether significant differences of speed existed among three distinct freestyle swimming racing starts. The three skills analyzed were: (1) the grab; (2) the arms back; and (3) the circular arm swing starts. Second, this investigator rendered a mechanical analysis and comparison of the three selected starts. The following sub-purposes were employed in the analysis to reveal the mechanical make-up of each start:

1. To compute and plot throughout the dive the center of gravity of each subject in a plane perpendicular to the lens of the camera.

2. To determine the reaction time of each subject to the starting command.

3. To determine the time interval between the command to start and the instant each subject's feet left the starting block.

4. To determine the total elapsed time for the dive which was from the starting command until the hands first made contact with the water.

5. To determine the take-off angle of the body's center of gravity from the starting block in a plane perpendicular to the lens of the camera.

6. To determine the take-off velocity of the body's center of gravity from the starting block measured in a plane perpendicular to the lens of the camera.

7. To determine the horizontal distance that each subject's center of gravity traversed during airborne flight.

8. To determine the time of airborne flight of each subject's center of gravity.

9. To determine the horizontal distance that each subject traversed during the dive.

10. To plot the trajectory of each subject's wrist in a plane perpendicular to the lens of the camera.

The cinematographic process was used to obtain the data for the analysis and comparison. A sequential mechanical description of each dive was compiled from the film. In addition, stick figures composed of link lines were constructed every twentieth of a second to further clarify the account.

Composite graphs relative to the trajectories of the wrist and body's center of gravity were made. They were utilized to furnish a more fluid description of the major similarities and dissimilarities noted during the start. Finally, a comparison of the computed and theoretical trajectories of the body's centers of gravity were made. It served to validate the center of gravity computations.

FINDINGS

An analysis of variance revealed that there were no significant differences of speed among three groups of swimmers that performed the three distinct freestyle starts.

A cinematographic analysis and comparison of three selected subjects revealed that, in general, the mechanical principles of the dives were congruent. The following properties relative to the sub-purposes of the study were realized:

1. <u>Initial reaction time to the starting command.</u>

   a. grab start subject - .21 seconds

   b. arms back subject - .19 second

   c. circular arm swing subject - .18 second

2. <u>Time of movement on the starting block.</u>

   a. grab start subject - .83 second

   b. arms back subject - .83 second

   c. circular arm swing subject - .89 second

3. <u>Total time of start.</u>

   a. grab start subject - 1.14 seconds

   b. arms back subject - 1.18 seconds

   c. circular arm swing subject - 1.22 seconds

4. <u>Take-off angle of center of gravity from starting block.</u>

   a. grab start subject - minus 15 degrees

   b. arms back subject - minus 11 degrees

   c. circular arm swing subject - minus 10 degrees

5. <u>Take-off velocity of center of gravity from starting block.</u>

   a. grab start subject - 14.3 feet/second

   b. arms back subject - 14.8 feet/second

   c. circular arm swing subject - 15.4 feet/second

6. <u>Range of body's center of gravity during airborne flight.</u>

   a. grab start subject - 4.33 feet

   b. arms back subject - 5.08 feet

   c. circular arm swing subject - 5.25 feet

7. Time of airborne flight of center of gravity.

a. grab start subject - .31 second

b. arms back subject - .35 second

c. circular arm swing subject - .33 second

8. Horizontal distance of dive from starting block to hand entry.

a. grab start subject - 12.0 feet

b. arms back subject - 12.6 feet

c. circular arm swing subject - 13.0 feet

9. Angle of take-off trajectory. Film analysis revealed that contrary to popular opinion the angle of take-off of each subject from the starting block was in a downward direction and not up.

The most readily apparent differences in body movement lay in the actions of the arms and centers of gravity. The following comparative movements were noted during execution of the starts:

1. Wrist. The greatest discrepancy among body movements lay in the wrist. The grab start subject's wrist trajectory began near the leading edge of the starting block and moved in a horizontal outward direction. During the initial stages of the start the apparent function of the arms was to push and pull

the body off the starting block. As the subject left the starting block the wrist continued in a convex parabolic trajectory toward the water.

At the onset of the skill the arms back subject's wrist trajectory began in a back horizontal position. Film observation revealed that the initial movement of the wrist was in a clockwise direction. As soon as the wrist had rotated to a vertical position it stopped and began movement in a counterclockwise direction. As the swimmer extended himself on the starting block, the wrist trajectory continued in a forceful counterclockwise direction. The forceful upward rotation of the arms through the fourth quadrant tended to lift the body off the starting block. Upon leaving the starting block the wrist trajectory moved in a convex parabolic direction.

The circular arm swing subject, at the onset of the skill, positioned his wrists slightly above and in front of the leading edge of the starting block. Initial wrist movement was in a counterclockwise direction. As the swimmer extended himself on the starting block the wrist gained greater rotary velocity. Upon leaving the starting block the wrist had prescribed a complete circle. The immediate cessation of rotary movement tended to lift and accelerate the upper torso off the starting block. As the body left the starting block the wrist continued in a convex parabolic trajectory.

Careful observation of the three subjects revealed that after initial movements the wrist trajectories appeared to be congruent. Thus, the effects of the arm movement upon total body trajectory had to occur during the beginning phases of the starts.

2. Center of gravity. The center of gravity trajectory for the grab start subject was different during the initial stages of the start than those of the other two. Due to the initial position his center of gravity was closer to the top of the starting block and slightly in front of it. At the onset of body movement his center of gravity moved in a downward and outward direction of about forty-five degrees. However, it soon began leveling off as the subject extended himself on the starting block. As he left the starting block his body was inclined in almost a horizontal position. During airborne flight his center of gravity traveled in a trajectory of a freely falling body.

In contrast to the trajectory of the grab start subject, the arms back and circular arm swing subject's paths were congruent to each other. At the onset of the skill their trajectories were more outward than downward at about an angle of thirty degrees. As they extended themselves on the starting block their centers of gravity continued moving in a straight line. Upon leaving the starting block their bodies were not as horizontal as that of the grab start subject. During airborne flight their centers of gravity traveled in a trajectory of a freely falling body.

When comparing the trajectories and body positions of the three swimmers three major dissimilarities were noted. First, the initial trajectory of the grab start subject was in a more downward direction than that of the other two. The reason for this was attributed to the action of the arms. As the grab start subject began movement, his hands, which were grasping the leading edge of the starting block, were pulling his body into a tight crouch. The arms back and circular arm swing subjects had no restriction upon their initial movement, thus they were able to move more outwardly. Second, the body position of the grab start subject as he left the starting block was more horizontal than those of the other two. Once again, this was ascribed to the actions of the arms. In part, the grab start subject did not appear to have as forceful a rotary motion of the arms as did the arms back and circular arm swing subjects. Therefore, the lifting tendency attributed to the former subject's arms was not present in the latter two. Third, the grab start subject did not dive as far into the race as the other two nor did he remain in the air as long.

CONCLUSIONS

Within the limitations of this study the following conclusions were made:

1. There were no significant differences of speed among three age-group freestyle racing starts.

2. In general, the movement patterns exhibited by the three filmed subjects representative of each start were the same.

3. The angle of take-off of each subject was in a downward direction.

4. Due to the prescribed nature of the arm patterns of each subject the greatest movement discrepancy was noted among the arms.

5. The center of gravity trajectories for the arms back and circular arm swing starts were

congruent while that of the grab start was not. Differences in trajectories were ascribed, in part, to the actions of the arms.

6. Apparently the grab start swimmer entered the water sooner but not as far out as the other two subjects.

7. A swimmer with poor starting mechanics and time might improve his overall swimming time if he were to employ the grab start and enter the race sooner.

8. From a mechanical standpoint the grab start appeared to be the simplest. The action of the arms was not as complicated as those of the arms back and circular arm swing starts. Therefore, swimmers should have little trouble understanding and applying the mechanics necessary to execute the skill.

9. However, when selecting a freestyle racing start age-group swimmers should experiment with all three starts and select the one that is most comfortable and economical to them.

RECOMMENDATIONS

Cinematographic studies of the racing dive should not stop with this study. The field of analyzing human performance will have increased scope as more valid and reliable studies are conceived. The investigator hopes that the knowledge and procedures developed in this study will contribute to this end. With these thoughts in mind the following recommendations are stated:

1. Additional studies using all age-groups as well as collegiate swimmers should be conducted.

2. More accurate methods of locating the center of gravity and determining the angle of take-off should be conducted.

3. Additional studies using swimmers with slow reactions and employing the grab start should be employed.

4. Additional studies in which each swimmer utilizes all three starts should be undertaken.

5. Additional studies in which the momentum producing body parts are isolated and identified should be undertaken.

6. Additional studies in which the subjects are participating in actual races should be undertaken.

7. Additional studies utilizing kinetic as well as kinematic function should be undertaken.

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APPENDICES

APPENDIX A

STARTING TIME IN SECONDS FOR THE FIRST FOURTEEN FEET OF A RACE FOR THREE GROUPS OF FREESTYLE SWIMMERS

	Grab Start		Circular Arm Start		Arms Back Start	
1.	C.M.	1.54	M.M.	1.73	K.R.	1.93
2.	G.M.	1.72	H.N.	1.80	B.M.	1.80
3.	A.P.	1.53	P.L.	1.69	K.R.	1.91
4.	B.S.	1.55	B.W.	1.68	B.H.	1.84
5.	B.J.	1.62	B.G.	1.64	W.N.	1.89
6.	S.T.	1.57	R.L.	2.10	B.R.	1.54
7.	R.A.	1.76	J.L.	1.98	C.L.	1.62
8.	B.A.	1.54	M.C.	1.66	L.A.	1.66
9.	R.M.	1.62	M.G.	1.61	T.C.	1.70
10.	A.P.	1.53	L.J.	1.83	T.L.	1.82
11.	M.R.	1.75	B.Y.	1.65	B.D.	1.83
12.	M.W.	1.78	A.R.	1.71	L.R.	1.90
13.	B.Z.	1.58	J.R.	1.59	H.C.	1.87
14.	S.B.	1.72	T.R.	1.66	G.N.	1.85
15.	H.S.	1.72	B.J.	1.61	R.M.	1.81
16.	D.J.	1.70	D.M.	1.65	F.D.	1.81
17.	B.T.	1.72	M.J.	1.83	B.N.	1.76
18.	B.N.	2.21	B.J.	1.65	R.S.	1.62
19.	T.M.	1.88	A.J.	1.69	C.M.	1.68
20.	L.C.	1.82	B.T.	1.70	D.S.	2.04
21.	R.D.	1.64	L.R.	1.84	J.B.	1.80
22.	P.S.	1.84	B.H.	1.82	S.H.	1.84
23.	J.F.	1.60	T.B.	1.72	E.D.	1.59
24.	T.O.	2.01	C.S.	1.80	S.S.	1.64
25.	J.B.	1.69	W.B.	1.70	R.W.	1.66
		42.64		43.34		44.40
	$\bar{M} = 1.71$		$\bar{M} = 1.73$		$\bar{M} = 1.77$	

APPENDIX B

RAW DATA UTILIZED BY THE SEGMENTAL METHOD FOR DETERMINING THE BODY'S CENTER OF GRAVITY TRAJECTORY DURING THE FREESTYLE RACING START OF THREE SWIMMERS

GRAB START

Body Segment	percentage weight		.00 and .10 Seconds		.20 Seconds	
			Horizontal[a]	Vertical[a]	Horizontal	Vertical
Head	.07	X	2=(.14)	13=(.91)	- 2=(- .14)	10=(.70)
Trunk	.43	X	11=(4.73)	--=(-----)	8=(3.44)	--=(----)
Upper Arm	.07	X	-- (----)	5=(.35)	- 2=(- .14)	4=(.28)
Lower Arm	.06	X	-13=(- .78)	1=(.06)	-14=(- .84)	--=(----)
Thigh	.23	X	6=(1.38)	- 3=(- .69)	3=(.69)	- 3=(- .69)
Leg	.14	X	- 9=(- 1.26)	- 2=(- .28)	-12=(- 1.68)	- 4=(- .56)
			6.25	1.32	4.13	- 1.25
			-2.04	-.97	-2.80	.98
			4.21	.35	1.33	- .27

a = Horizontal and Vertital distances expressed in millimeters that the body's segment center of gravity was located from arbitrarily drawn horizontal and vertical lines located near the subject's hip joint.

Note: Refer to "Segmental Method" in Chapter II for a complete explanation of the above figures.

APPENDIX B (continued)

GRAB START

.30 Seconds Horizontal	.30 Seconds Vertical	.40 Seconds Horizontal	.40 Seconds Vertical	.50 Seconds Horizontal	.50 Seconds Vertical
- 3=(- .21)	10=(.70)	- 3=(- .21)	11=(.77)	3=(.21)	14=(.98)
7=(3.01)	--=(---)	7=(3.01)	--=(---)	8=(3.44)	--=(---)
- 3=(- .21)	4=(.28)	- 2=(- .14)	4=(.28)	--=(---)	3=(.21)
-12=(- .72)	- 1=(- .06)	-11=(- .66)	- 3=(- .18)	- 8=(- .48)	- 5=(- .30)
2=(.46)	- 3=(- .69)	2=(.46)	- 2=(- .46)	3=(.69)	- 5=(-1.15)
-11=(-1.54)	- 4=(- .56)	-10=(-1.40)	- 5=(- .70)	5=(.70)	- 7=(- .98)
3.47	-1.31	3.47	-1.34	4.34	-2.43
-2.68	.98	-2.41	1.05	-1.18	1.19
.79	- .33	1.06	- .29	3.16	-1.24

.60 Seconds Horizontal	.60 Seconds Vertical	.70 Seconds Horizontal	.70 Seconds Vertical	.80 Seconds Horizontal	.80 Seconds Vertical
3=(.21)	15=(1.05)	4=(.28)	15=(1.05)	6=(.42)	13=(.91)
7=(3.01)	--=(---)	9=(3.87)	--=(---)	5=(2.15)	5=(2.15)
- 1=(- .07)	7=(.49)	--=(---)	12=(.84)	1=(.07)	14=(.98)
-13=(- .78)	5=(.30)	- 9=(- .54)	18=(1.08)	- 7=(- .42)	29=(-2.76)
- 2=(- .46)	- 2=(- .46)	--=(---)	- 7=(-1.61)	-16=(-2.24)	-12=(-2.76)
- 6=(- .84)	- 9=(-1.26)	- 4=(- .56)	-16=(-2.24)	- 3=(- .42)	-29=(-4.06)
3.22	1.84	4.15	-3.85	2.64	-6.82
-2.12	-1.72	-1.10	2.97	-1.07	5.78
1.10	.12	3.05	- .88	1.57	-1.04

APPENDIX B (continued)

GRAB START

.83 Seconds		.86 Seconds		.90 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
6=(.42)	16=(1.12)	4=(.28)	17=(1.19)	4=(.28)	19=(1.33)
3=(1.29)	3=(1.29)	½=(.21)	3=(1.29)	½=(.21)	5=(2.15)
--=(---)	18=(1.26)	- ½=(- .03)	18=(1.26)	- 1=(- .07)	21=(1.47)
- 7=(- .42)	27=(1.62)	- 7=(- .42)	29=(1.74)	- 6=(- .36)	32=(1.92)
--=(---)	-16=(-3.68)	½=(.11)	-15=(-3.45)	1=(.23)	-12=(-2.76)
- 2=(- .28)	-33=(-4.62)	3=(.42)	-33=(-4.62)	4=(.56)	-30=(-4.20)
1.71	-8.30	1.02	-8.07	1.28	-6.96
- .70	5.29	- .45	5.48	- .43	6.87
1.01	-3.01	.57	-2.59	.85	- .09

1.00 Seconds		1.10 Seconds		1.14 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
½=(.03)	20=(1.40)	- 3=(- .21)	18=(1.26)	- 3=(- .21)	17=(1.19)
- ½=(- .21)	4=(1.72)	--=(---)	4=(1.72)	1=(.43)	2=(.86)
½=(.03)	20=(1.40)	--=(---)	20=(1.40)	- 2=(- .14)	18=(1.26)
- 4=(- .24)	30=(1.80)	- 4=(- .24)	31=(1.86)	- 6=(- .36)	28=(1.68)
2=(.46)	-13=(-2.99)	3=(.69)	-13=(-2.99)	5=(1.15)	-15=(-3.45)
11=(1.54)	-30=(-4.20)	14=(1.96)	-29=(-4.06)	14=(1.96)	-32=(-4.48)
2.06	-7.19	2.65	-7.05	3.54	-7.93
- .45	6.32	- .45	6.24	- .71	5.09
1.61	- .87	2.20	- .81	2.83	-2.84

APPENDIX B (continued)

ARMS BACK START

.00 and .10 Seconds		.20 Seconds		.30 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
- 4=(- .28)	11=(.77)	- 4=(- .28)	11=(.77)	- 8=(- .56)	6=(.42)
7=(3.01)	½=(.21)	7=(3.01)	½=(.21)	4=(1.72)	2=(.86)
1=(.07)	2=(.14)	1=(.07)	2=(.14)	3=(.21)	5=(.35)
7=(.42)	-12=(- .72)	10=(.60)	-11=(- .66)	15=(.90)	1=(.06)
- 1=(- .23)	- 6=(-1.38)	- 1=(- .23)	- 6=(-1.38)	- 1=(-1.38)	- 4=(- .92)
-18=(-2.52)	- 5=(- .70)	-18=(-2.52)	- 5=(- .70)	-19=(-2.66)	- 6=(- .64)
3.50	-2.80	3.68	-2.72	-3.45	1.69
-3.03	1.12	-3.03	1.12	2.83	-1.56
.47	-1.68	.65	-1.60	- .62	.13

.40 Seconds		.50 Seconds		.60 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
- 7=(- .49)	8=(.56)	- 3=(- .21)	11=(.77)	2=(.14)	15=(1.05)
4=(1.72)	2=(.86)	5=(2.15)	--=(----)	5=(2.15)	2=(.86)
4=(.28)	5=(.35)	2=(.14)	- 1=(- .07)	- 5=(- .35)	10=(.70)
11=(.66)	2=(.12)	8=(.48)	-12=(- .72)	-18=(-1.08)	11=(.66)
- 1=(- .23)	- 4=(- .92)	- 1=(- .23)	- 5=(-1.15)	- 5=(-1.15)	- 3=(- .69)
-18=(-2.52)	- 8=(-1.12)	-14=(-1.96)	-10=(-1.40)	-14=(-1.96)	-12=(-1.68)
-3.24	-2.04	2.77	-3.34	-4.54	3.27
2.66	1.89	-2.40	.77	2.29	-2.37
- .58	- .15	.37	-2.57	-2.25	.90

APPENDIX B (continued)

ARMS BACK START

.70 Seconds		.80 Seconds		.83 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
5=(.35)	14=(.98)	8=(.56)	14=(.98)	9=(.63)	13=(.91)
5=(2.15)	3=(1.29)	4=(1.72)	2=(.86)	2=(.86)	--=(---)
1=(.07)	16=(1.12)	3=(.21)	17=(1.19)	2=(.14)	15=(1.05)
- 4=(- .24)	28=(1.68)	- 2=(- .12)	27=(1.62)	- 7=(- .42)	25=(1.50)
-2½=(- .57)	- 7=(-1.61)	- 1=(- .23)	-15=(-3.45)	- 1=(- .23)	-17=(-3.91)
- 9=(-1.26)	-18=(-2.56)	- 7=(- .98)	-31=(-4.35)	- 6=(- .84)	-34=(-4.76)
2.57	5.07	2.49	-7.80	1.63	-8.67
-2.05	-4.17	-1.33	4.65	-1.49	3.46
.52	.90	1.16	-3.15	.14	-5.12

.86 Seconds		.90 Seconds		1.00 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
9=(.63)	15=(1.05)	8=(.56)	17=(1.19)	5=(.35)	15=(1.05)
2=(.86)	3=(1.29)	2=(.86)	6=(2.58)	1=(.43)	4=(1.72)
2=(.14)	16=(1.12)	- 1=(- .07)	18=(1.36)	--=(----)	17=(1.19)
- 7=(- .42)	25=(1.50)	- 7=(- .42)	27=(1.62)	- 7=(- .42)	27=(1.62)
- 2=(- .46)	-14=(-3.22)	- 2=(- .46)	-11=(-2.53)	--=(----)	-15=(-3.45)
- 2=(- .24)	-32=(-4.48)	- 1=(- .14)	-30=(-4.20)	4=(.56)	-33=(-4.62)
1.63	-7.70	1.42	6.75	1.34	-8.07
-1.16	4.96	-1.09	-6.73	- .42	5.58
.47	-2.74	.33	.02	.92	-2.49

APPENDIX B (continued)

ARMS BACK START

1.10 Seconds		1.18 Seconds	
Horizontal	Vertical	Horizontal	Vertical
- 3=(- .21)	17=(1.19)	- 5=(- .35)	11=(.77)
--=(---)	4=(1.72)	--=(---)	1=(.43)
- 1=(- .07)	18=(1.36)	- 1=(- .07)	15=(1.05)
- 5=(- .30)	29=(1.74)	- 3=(- .18)	28=(1.88)
2=(.46)	-15=(-3.45)	6=(1.38)	-18=(-4.14)
6=(.64)	-32=(-4.48)	7=(.98)	-34=(-4.76)
1.10	-7.93	2.36	-8.90
- .58	6.01	- .60	3.98
.52	-1.92	1.76	-4.97

APPENDIX B (continued)

CIRCULAR ARM SWING START

.00 and .10 Seconds		.20 Seconds		.30 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
1=(.07)	10=(.70)	- 3=(- .21)	9=(.63)	- 5=(- .35)	8=(.56)
9=(3.87)	--=(---)	7=(3.01)	- 2=(- .86)	7=(3.01)	--=(---)
- 1=(- .07)	9=(.63)	1=(.07)	8=(.63)	--=(---)	7=(.49)
- 7=(- .42)	14=(.84)	- 7=(- .42)	13=(.78)	3=(.18)	14=(.84)
4=(.92)	- 8=(-1.84)	3=(.69)	- 7=(-1.61)	2=(.46)	- 5=(-1.15)
-14=(-1.96)	- 5=(- .70)	-14=(-1.96)	- 6=(- .84)	-14=(-1.96)	- 6=(- .84)
4.86	-2.54	3.77	-3.31	3.65	-1.99
-2.45	2.17	-2.59	1.97	-2.31	1.89
2.41	- .37	1.18	-1.34	1.34	- .10

.40 Seconds		.50 Seconds		.60 Seconds	
Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical
- 7=(- .49)	9=(.63)	- 4=(- .28)	12=(.84)	- 2=(- .14)	15=(1.05)
7=(3.01)	2½=(1.07)	8=(3.44)	--=(---)	5½=(2.36)	2=(.86)
3=(.21)	8=(.56)	6=(.42)	2=(.14)	1=(.07)	2=(.14)
13=(.78)	11=(.66)	19=(1.14)	- 7=(- .42)	- 2=(- .12)	-12=(- .72)
-13=(-1.82)	- 3=(- .69)	3=(.69)	- 5=(-1.15)	- 2=(- .46)	- 3=(- .69)
3=(.69)	- 5=(- .70)	-12=(-1.68)	-10=(-1.40)	-13=(-1.82)	-10=(-1.40)
4.69	2.92	5.69	-2.97	-2.54	-2.81
-2.31	-1.39	-1.96	.98	2.43	2.05
2.38	1.53	3.73	-1.99	- .11	- .76

APPENDIX B (continued)

CIRCULAR ARM SWING START

.70 Seconds

Horizontal	Vertical
3=(.21)	17=(1.19)
7=(3.01)	2=(.86)
- 3=(- .21)	11=(.77)
-17=(-1.02)	15=(.90)
- 4=(- .92)	- 4=(- .92)
-12=(-1.68)	-13=(-1.82)
-3.83	3.72
3.22	-2.74
- .61	.98

.80 Seconds

Horizontal	Vertical
6=(.42)	18=(1.26)
5=(2.15)	3=(1.29)
--=(---)	17=(1.19)
- 6=(- .36)	30=(1.80)
- 2=(- .46)	-10=(-2.30)
- 9=(-1.26)	-24=(-3.36)
2.57	-5.66
-2.08	5.54
.49	- .12

.90 Seconds

Horizontal	Vertical
9=(.63)	15=(1.05)
3=(1.29)	3=(1.29)
1=(.07)	16=(1.12)
-10=(- .60)	26=(1.56)
- 1=(- .23)	-16=(-3.68)
- 5=(- .70)	-32=(-4.48)
2.09	-8.16
-1.53	5.02
.56	-3.14

.93 Seconds

Horizontal	Vertical
11=(.77)	15=(1.05)
3=(1.29)	3=(1.29)
2=(.14)	16=(1.12)
- 8=(- .48)	25=(1.50)
- 1=(- .23)	-15=(-3.45)
- 1=(- .14)	-33=(-4.62)
2.20	-8.07
- .85	4.96
1.35	-3.11

1.00 Seconds

Horizontal	Vertical
9=(.63)	16=(1.12)
1=(.43)	3=(1.29)
--=(---)	17=(1.19)
-10=(- .60)	25=(1.50)
- 1=(- .23)	-14=(-3.22)
- 1=(- .14)	-32=(-4.48)
-1.43	-7.70
1.06	5.10
- .37	-2.60

1.10 Seconds

Horizontal	Vertical
7=(.49)	18=(1.26)
2=(.86)	3=(1.29)
1=(.07)	17=(1.19)
- 8=(-.48)	28=(1.68)
1=(.23)	-16=(-3.68)
4=(.56)	-33=(-4.62)
2.21	-8.30
- .48	5.42
1.73	-2.88

APPENDIX B (continued)

CIRCULAR ARM SWING START

1.20 Seconds		1.22 Seconds	
Horizontal	Vertical	Horizontal	Vertical
- 3=(- .21)	18=(1.26)	- 5=(- .35)	15=(1.05)
2=(.86)	4=(1.72)	2=(.86)	2=(.86)
- 1=(- .07)	19=(1.33)	- 3=(- .21)	17=(-1.19)
- 9=(- .54)	31=(1.86)	-10=(- .60)	28=(1.68)
2=(.46)	-15=(-3.45)	2=(.86)	-17=(-3.91)
4=(.56)	-33=(-4.62)	4=(.56)	-34=(-4.76)
1.88	-8.07	1.88	-8.67
- .82	6.17	-1.06	4.76
1.06	-1.90	.82	-3.89

VITA

VITA

The author was born in Malad City, Idaho on September 25, 1943. He was the third of seven children. A few years later the family moved to Greenville, North Carolina where he spent the majority of his life.

He attended elementary and high school in Greenville and graduated from J. H. Rose High School in 1961. Upon graduation the author entered East Carolina University. After a year and a half of study he embarked upon a mission to Uruguay in the service of The Church of Jesus Christ of Latter-Day Saints, commonly known as the "Mormon" Church. Returning in 1965 after a successful mission tour the author re-entered East Carolina University and graduated in May, 1967 with a Bachelor of Science degree in Physical Education and Spanish. Continuing his education the author graduated in August, 1968 with a Master of Science degree in Physical Education.

In September, 1968 he entered Louisiana State University to continue work on an advanced degree. In addition, the author was employed under a graduate administrative assistantship as athletic coach in swimming. He remained as a full-time student until August, 1970. All course requirements except completion of a dissertation had been fulfilled during his sojourn at Louisiana State University.

After leaving Louisiana State University, the author accepted the position of Assistant Professor of Physical Education at Pan American College in Edinburg, Texas.

He is married to the former Karen Ann Lox of Roanoke, Virginia. They are the parents of twin boys, Hunter Christian and Lance Richmond.

EXAMINATION AND THESIS REPORT

Candidate: Layne Winslow Jorgensen

Major Field: Physical Education

Title of Thesis: A Cinematographic and Descriptive Comparison of Three Selected Freestyle Racing Starts in Competitive Swimming

Approved:

[illegible]
Major Professor and Chairman

Max Goodrich
Dean of the Graduate School

EXAMINING COMMITTEE:

Max L. Lyle

Paul Adams

Helen E. Fant

Ralph E. Steben

Date of Examination:

July 19, 1971